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X-15: THE PERSPECTIVE OF HISTORY

Good afternoon. It is a pleasure to be here today discussing the X-15. Unlike the rest of the speakers, I never had the opportunity to play any role whatsoever in the story of the X-15. I know what you're thinking: "Here we work all these years, and this guy shows up in time for the party."

In fact, never having had the opportunity to see the X-15 fly, much less to play any sort of role in its story, is one of my great regrets, for I believe that, as time goes on and as our perspective on the history of aviation improves, the significance of the X-15 becomes even more apparent.

Two major events occurred in aerospace in 1969. One of these, which has already been deservedly celebrated and will continue to be so, is, of course, the voyage of Apollo 11 to Tranquility Base (figs. 1 and 2). The second, which is apparent to all of us, was the retirement of the X-15 (fig. 3) from flight testing after 199 flights. Between these two programs were significant links. The most readily apparent was the selection of an X-15 veteran, Neil Armstrong, to command the Apollo mission. But there were less obvious, but nevertheless important, linkages between the technology and management of the two programs, and it is worth noting a few of these.

The X-15 follow-on program, approved in 1962, oriented X-15 research towards the national space effort. An MIT-sponsored horizon definition experiment benefited navigation equipment used on Apollo for the return to Earth, and the X-15 carried experimental insulation test panels evaluated for use on the Saturn booster. The so-called High Range developed for the X-15 (fig. 4)—more precisely called the Project 1226 Radar Range—anticipated and influenced the subsequent NASA Manned Spacecraft Tracking Network that supported the Mercury, Gemini, and Apollo programs, and expanded, then, to meet the subsequent needs of the Apollo-Soyuz Test Project, Skylab, and shuttle. The requirement for full-time physiological protection for the X-15's pilots led to creation of the first practical "production" space suits, and subsequently influenced suit development for the national space program (fig. 5). The X-15 was a true aerospace system, operating both within and outside the atmosphere (fig. 6). On August 22, 1963, NASA pilot Joe Walker (fig. 7) reached an altitude of 354,200 ft (67 mi), performing a shuttle-style reentry from that altitude. Simulation requirements for the X-15 led to a variety of imaginative inflight approaches (figs. 8 and 9) that complemented ground simulation developments. The NACA-NASA management team that had administered the early X- series program at the Flight Research Center was deservedly plundered to provide key personnel for the

manned space effort, and, because of this—and in contrast to the Soviet space program—they brought a pronounced flight test philosophy into the running of the space program. Indeed, during the critical early days of both the X-15 and Project Mercury, Paul Bikle spoke for many when he termed them a “... parallel, two-pronged approach to solving some of the problems of manned space flight. While Mercury was demonstrating man’s capability to function effectively in space, the X-15 was demonstrating man’s ability to control a high-performance vehicle in a near-space environment” (fig. 10). This figure, from 1961, demonstrates how program planners envisioned the partnership of the X-15 and the Mercury programs. So the X-15 contributed greatly to what we may call the technological culture of the national space program. John Becker, one of the X-15’s founding fathers, recognized its uniqueness in 1969 when he received the Eugen Sänger Medal on behalf of the X-15 team, remarking that “The X-15 program was the first major investment of the United States in manned aerospace flight technology.”

It was Eugen Sänger, in fact, who had first proposed the development of winged hypersonic vehicles, starting in the late 1920’s (fig. 11), continuing with his antipodal aircraft studies of the 1930’s and 1940’s (fig. 12), and this interest helped stimulate a climate that resulted in the first attempt at a high supersonic winged vehicle, the A-4b of 1945 (fig. 13). In the postwar years, this interest continued via popularization by artist Chesley Bonestell (figs. 14 and 15). But there was considerable technical interest as well, building on the accomplishments of the X-1 and the early X-series (figs. 16 and 17), the experience of the advanced X-1’s and X-2 (figs. 18 and 19), and actual conceptual studies such as the Douglas D-558-3 (fig. 20) and the Drake-Carman studies conducted here at Dryden (fig. 21). The result of this inter- and intra-agency activity spawned the X-15, which was, for its time, an extraordinarily bold concept (fig. 22).

I think it is fair to state that the achievements of the X-15 greatly exceeded the expectations of its developers. Intended primarily as a hypersonic aerodynamics research tool, it instead provided a wealth of information in many other areas as well, including structures and materials, piloting problems, flight control system design and effectiveness, the interaction of aerodynamic and reaction control systems, guidance and navigation, and terminal area approach and landing behavior. It served as a testbed for a variety of space-related experiments, 28 of which were in the field of space sciences, ranging from astronomy to micrometeorite collection. Overall, the X-15 was a fitting successor to the X-1, for as the X-1 had furnished a focus and stimulus for supersonic research, the X-15 did so for hypersonic studies. As of May 1968, the program had resulted in 766 technical reports, equivalent to the full-time research effort of a 4000-person Federal research center working for 2 years.

In a special analytical study of the X-15 program completed in 1969, John Becker noted fully 66 accomplishments from the X-15 program. A sampling of the more significant, based in large measure upon the Becker study, includes:

- Development and demonstration of the first large, restartable, “man-rated,” throttleable rocket engine, the XLR-99.
- First application of hypersonic theory and wind tunnel work to an actual flight vehicle.
- Development of the wedge tail configuration to resolve hypersonic directional stability problems.
- First use of reaction controls for attitude control in space (fig. 23).
- First use of a reusable superalloy structure capable of withstanding the anticipated temperatures and thermal gradients of hypersonic reentry (fig. 24).
- Development of new fabrication techniques for the machining, forming, welding, and heat treating of Inconel-X and titanium.
- Development of improved high-temperature seals and lubricants.
- Development of the NACA Q-ball hot-nose flow-direction sensor for operation over an extreme range of dynamic pressures and a stagnation air temperature of 1900 °C.

- Development of the first practical full-pressure suit for pilot protection in space.
- Development of nitrogen cabin air-conditioning.
- Development of inertial flight data systems capable of functioning in a high-dynamic pressure and space environment.
- Discovery that hypersonic boundary layer flow was turbulent and not laminar.
- Discovery that turbulent heating rates were significantly lower than had been predicted by theory.
- First direct measurement of hypersonic skin friction, and the discovery that skin friction was lower than had been predicted.
- Discovery of “hot spots” generated by surface irregularities.
- Discovery of methods to correlate base-drag measurements with tunnel test results so as to correct wind tunnel prediction data.
- Development of practical boost-guidance pilot displays.
- Demonstration of a pilot’s ability to control a rocket-boosted aerospace vehicle through atmospheric exit.
- Development of large, supersonic drop tanks.
- Demonstration of successful transition from aerodynamic controls to reaction controls and back again.
- Demonstration of a pilot’s ability to function in a weightless environment.
- First demonstration of piloted, lifting atmospheric reentry.
- First application of energy management techniques to flight planning and terminal entry maneuvering.
- First development of a comprehensive real-time intermetted flight test and safety range incorporating a mission control center, flightpath predictive analysis, and physiological monitoring capabilities.

The X-15’s research program did not proceed with great smoothness or lack of difficulty (fig. 25). Indeed, one of the important aspects of the X-15 experience was the degree to which it offered cautionary lessons for subsequent high-performance vehicle development. While landing from its first glide flight, for example, the X-15 experienced severe pitching motions due to inadequate control rate response, and only the skill of pilot Scott Crossfield (fig. 26) prevented a loss of the aircraft. A series of ground and inflight accidents marred the contractor program, including recalcitrant APU’s, engine fires, and explosions—one of which virtually destroyed the X-15 No. 3. Technical problems forced delays with the large XLR-99 engine that prevented the X-15 from achieving its Mach 6 design goal until 1961.

During the remainder of the Government’s research program, annoying difficulties cropped up that had to be addressed. The propellant system was plagued with problems afflicting its pneumatic vents and relief valves. Manufacturing problems resulted in mechanics having to reject up to 30 percent of spare parts as unusable, a clear indication of the difficulties of devising industrial manufacturing and acceptance test procedures when building a system for use at the frontiers of science. Thermal stresses fractured the outer cockpit windshields, forcing a redesign of the cockpit framing from Inconel to titanium, and replacement of the original soda-lime glass to alumina-silica glass. Heating interactions from hot vortex flow generated by four expansion slots in the wing leading edge caused wing skin buckling during a flight to Mach 5.3, forcing redesign and strengthening. Panel flutter plagued the X-15 at airspeeds above Mach 2.4, forcing panel redesign on both the X-15 and the proposed Boeing X-20 Dyna-Soar

then under development. The original Sperry inertial guidance unit proved so unsatisfactory that it had to be replaced by a Honeywell unit first designed for the X-20. A complete electrical failure during a Mach 4+ climbout past 100,000 ft would have resulted in the loss of one X-15, save for the superb piloting of Pete Knight (fig. 27) who earned a well-deserved DFC for returning it safely to earth. An engine failure and subsequent landing gear collapse resulted essentially in the destruction of the X-15 No. 2, which North American rebuilt as the much-modified X-15A-2 (fig. 28).

Then, during preliminary testing of this aircraft, unanticipated thermal-induced stresses tripped the nose gear downlock, resulting in two cases of Mach 5 gear extension. In both cases, excellent piloting by Bob Rushworth (fig. 29) saved the day. On its maximum performance flight out to Mach 6.7 (fig. 30), piloted by Pete Knight, this aircraft experienced near-destructive heating effects due to poor understanding—and consequent prediction—of heating interactions and the ability of an experimental ablative coating to cope with the added stresses of a near-Mach 7 thermal environment.

Finally, and tragically, a combination of a physiological predisposition to vertigo, distraction, and some control system degradation from an electrical disturbance, and a total control system failure triggering a limit-cycle oscillation of the Honeywell adaptive flight control system, led to the loss of the X-15 No. 3 and pilot Mike Adams in November 1967. Contributing to the accident were inadequacies in the amount and type of information available to ground controllers. These deficiencies were subsequently corrected.

Overall, the problems and nuances of X-15 operations meant that, on an average, the X-15 completed 1.77 flights/month, a figure comparing well with the shuttle's own subsequent experience up to the loss of the Challenger in 1986.

While the X-15 generally showed remarkable agreement between its flight results and those of ground predictive tools, including wind tunnels and simulators, blunt aft end drag proved 15 percent higher on the actual aircraft than tunnel tests had predicted. Oddly enough, the wedge tail, incorporated to improve hypersonic directional stability, actually contributed to a potentially serious hypersonic roll instability and prevented the aircraft from being flown safely at angles of attack greater than 20°. Removing the lower half of the ventral fin—designed to be jettisoned anyway so that the landing skids could be employed—reduced stability, but greatly improved the pilot's ability to control the airplane. With the ventral off, the X-15 could now fly into the previously “uncontrollable” region, and, indeed, was eventually flown on reentry profiles up to 26° AOA, with flightpath angles of -38° and speeds up to Mach 6, presenting much more demanding piloting tasks than the shallow entries subsequently flown by manned vehicles returning from orbital or lunar missions. The relatively conventional straight-wing configuration of the X-15 resulted in high-impact loadings at landing (fig. 31) and contributed to at least two accidents. A proposed delta-wing modification to the X-15 never flew (following the loss of the X-15 No. 3), thus preventing a comparison of landing, high-speed, and heating characteristics between the two configurations.

Nevertheless, despite a plethora of straight- and swept-wing orbiter studies during the conceptualization of the shuttle (fig. 32) itself, there was little doubt that it would be a delta of some sort, in part because of the accumulated data from the X-15 program, and companion efforts such as the ASSET (fig. 33), the cancelled X-20 Dyna-Soar (fig. 34), and the lifting body effort (fig. 35).

Unexpectedly, aerospace medical researchers found that heart rates of X-15 pilots varied between 145 and 180 beats/min in flight, compared to a norm of 70–80 beats/min for research flights in other aircraft. Researchers eventually concluded that *prelaunch anticipatory stress*, rather than *postlaunch physical stress*, influenced the heart rate.

Overall, as I believe this quick overview of the results indicates, the X-15 was an important step on the road to the space shuttle. Because of its development, researchers acquired a keen appreciation of how even small and seemingly insignificant aspects of a configuration could have potentially profound implications for its safety and utility. Such lessons cropped up on subsequent programs as well, including the contemporary Mercury, Gemini, Apollo, ASSET, PRIME, and lifting body programs. Each technological generation has to learn this lesson for itself, however, and it is unfortunate that the seven Challenger astronauts had to pay with their lives for others' inadequate appreciation

of this basic truth and seeming inability to learn from previous programs. The lessons were certainly there to be studied, for the researchers of the X-15—you in the audience—did your jobs spectacularly well. You created the finest and most productive of the research aircraft that we have yet seen, and you established a standard by which all subsequent research aircraft programs must be judged. For this, I salute you. Thank you very much.

QUESTIONS AND ANSWERS

(Audience) How much did the Lockheed X-7 program contribute to the X-15?

(Hallion) I personally never found any evidence that the X-7 contributed to the X-15. I have found some interesting things on the X-7, however. One is the X-7 contributed first of all to the design of the F-104's wing interestingly enough. They were looking at flutter margins on the F-104's wing and tried to model these, if you will, on the X-7. The X-7 was an interesting little program. For those of you unfamiliar with it, it was basically a small, straight-winged vehicle with a relatively conventional tail layout that was air-launched from B-29 or B-50 bombers, basically the old Boeing Superfortress. It was powered by a series of ramjet engines, some of which were fairly small, some of which were rather large. The contributions of the X-7, as far as I can tell, were primarily related to evaluating the performance of ramjet engine technology and not really related primarily to other aerospace vehicles per se. I would say that there may have been some influence from that program, not on the X-15 but possibly, I would think, in a tangential sense, on the SR-71 program or what became the SR-71 program.



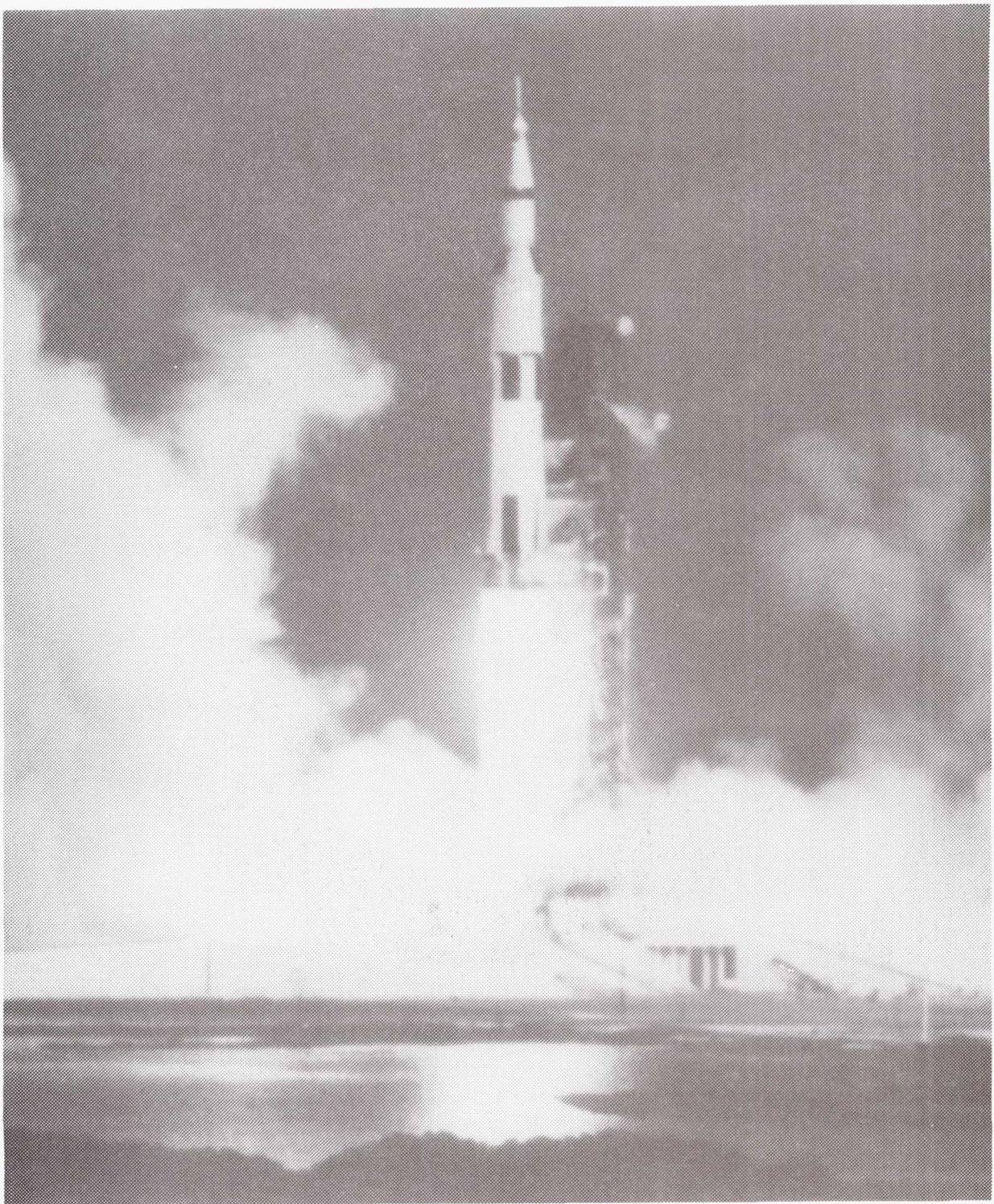


Figure 1. Launch of Apollo 11.

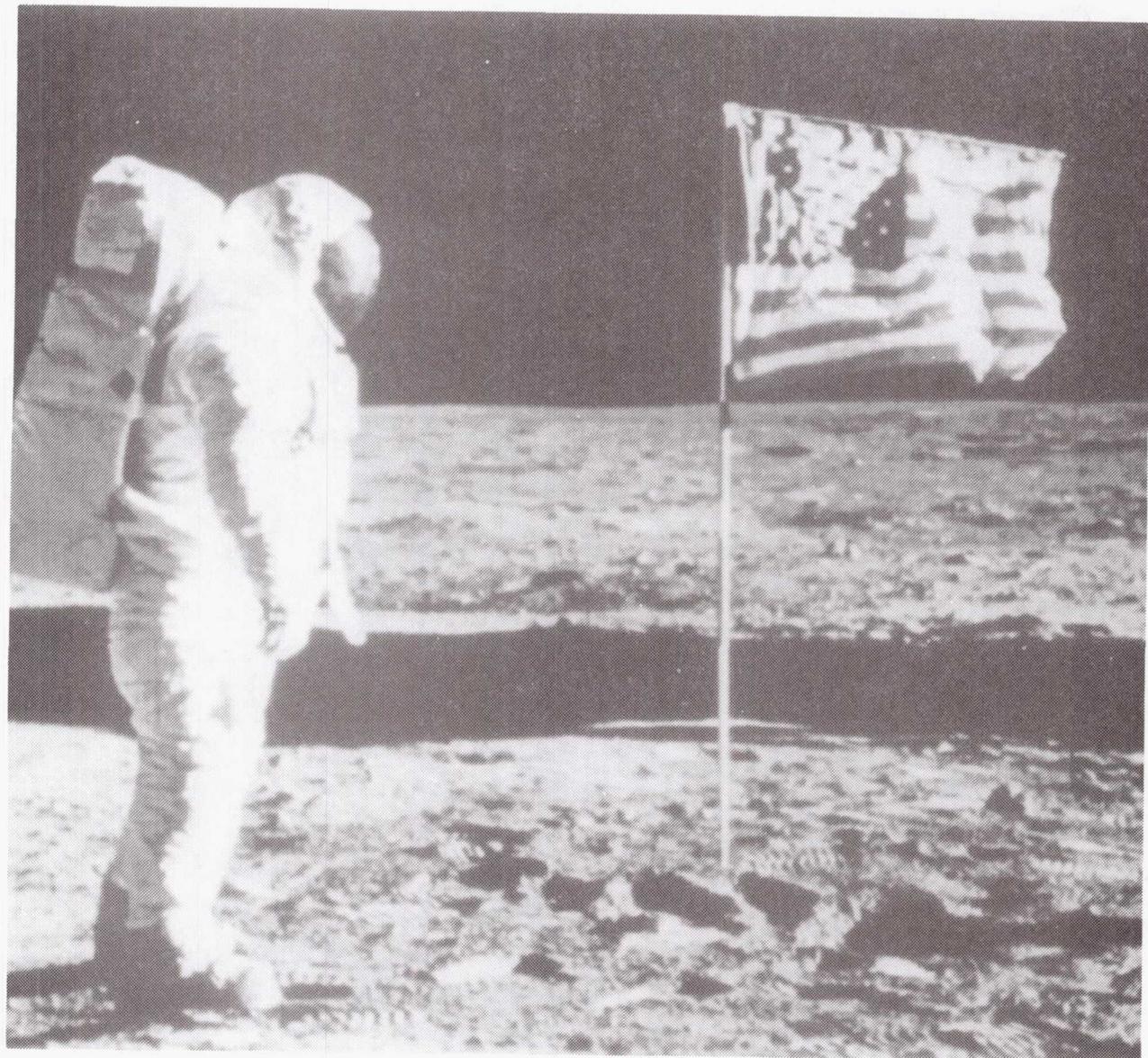


Figure 2. Tranquility Base.

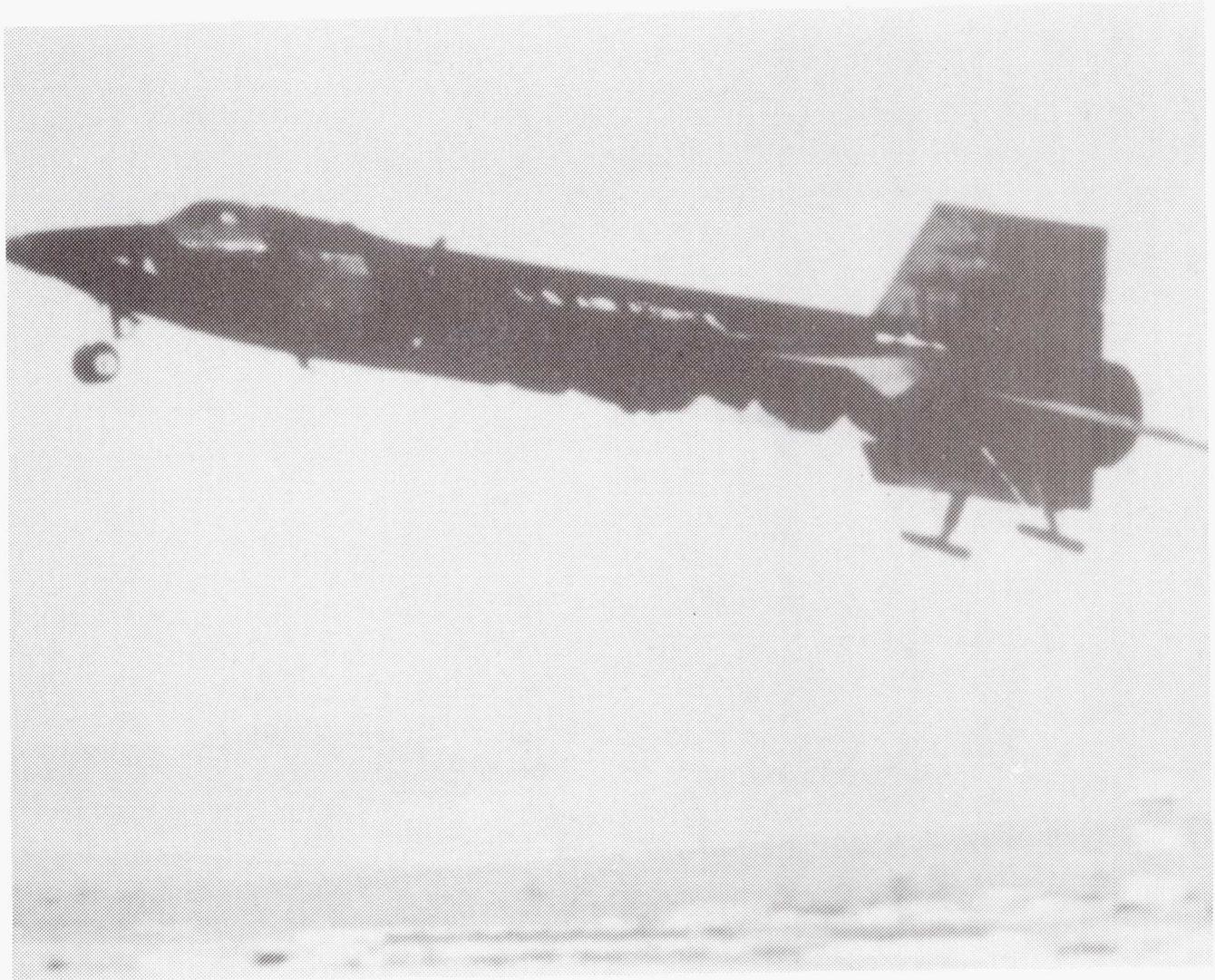


Figure 3. Return from X-15 final flight test.

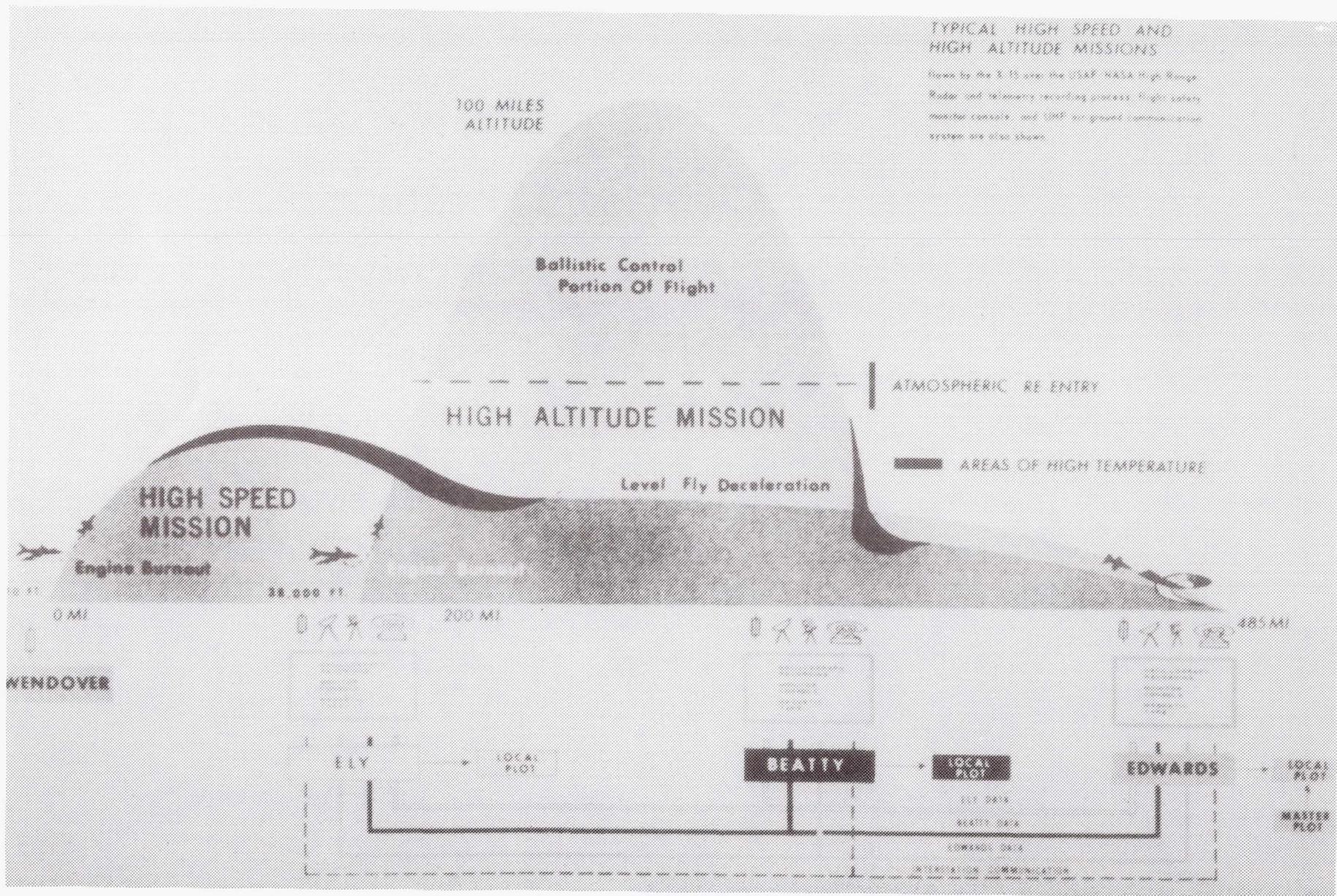


Figure 4. Project 1226 Radar Range.

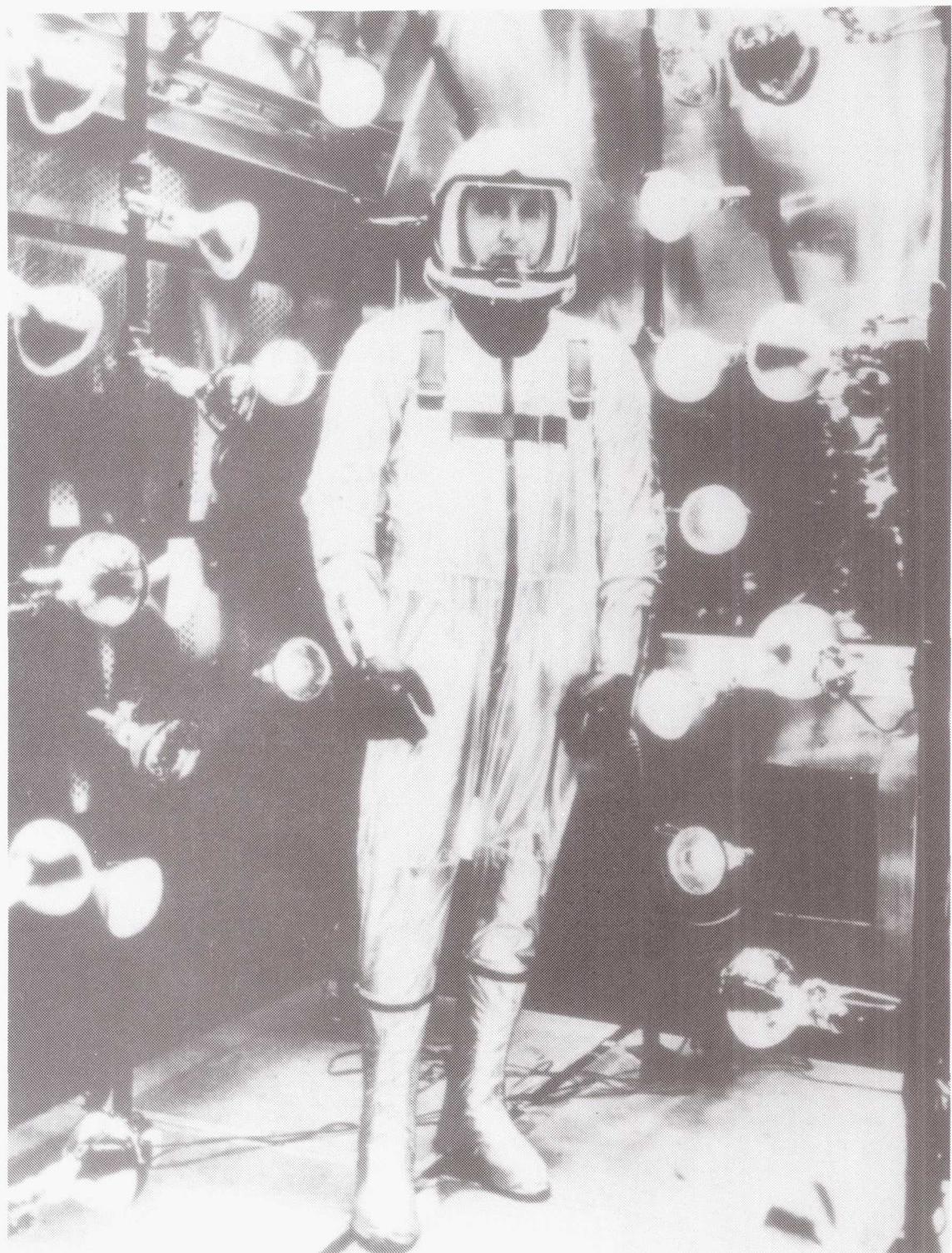


Figure 5. Early example of a space suit.

X-15 RESEARCH SYSTEM 350,000-FT MISSION

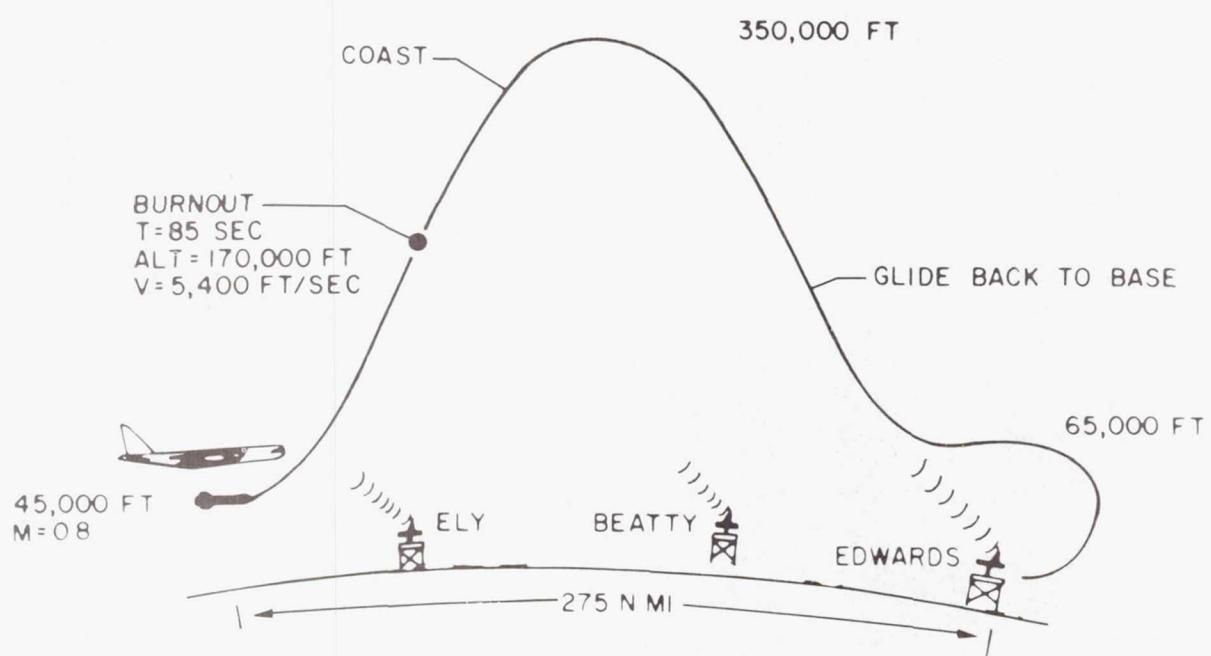


Figure 6. Aerospace environment of X-15 mission.

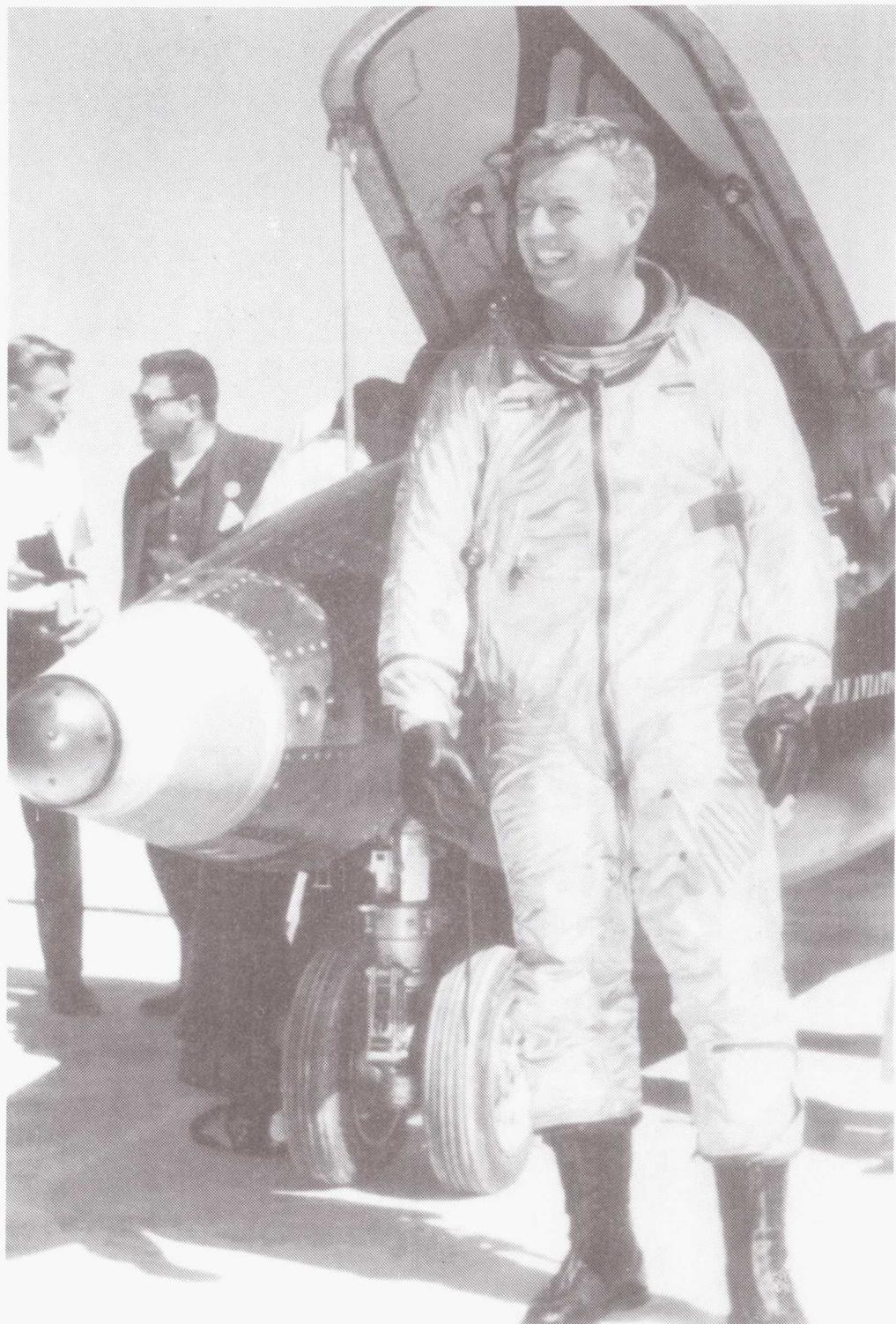


Figure 7. NASA research pilot Joe Walker.

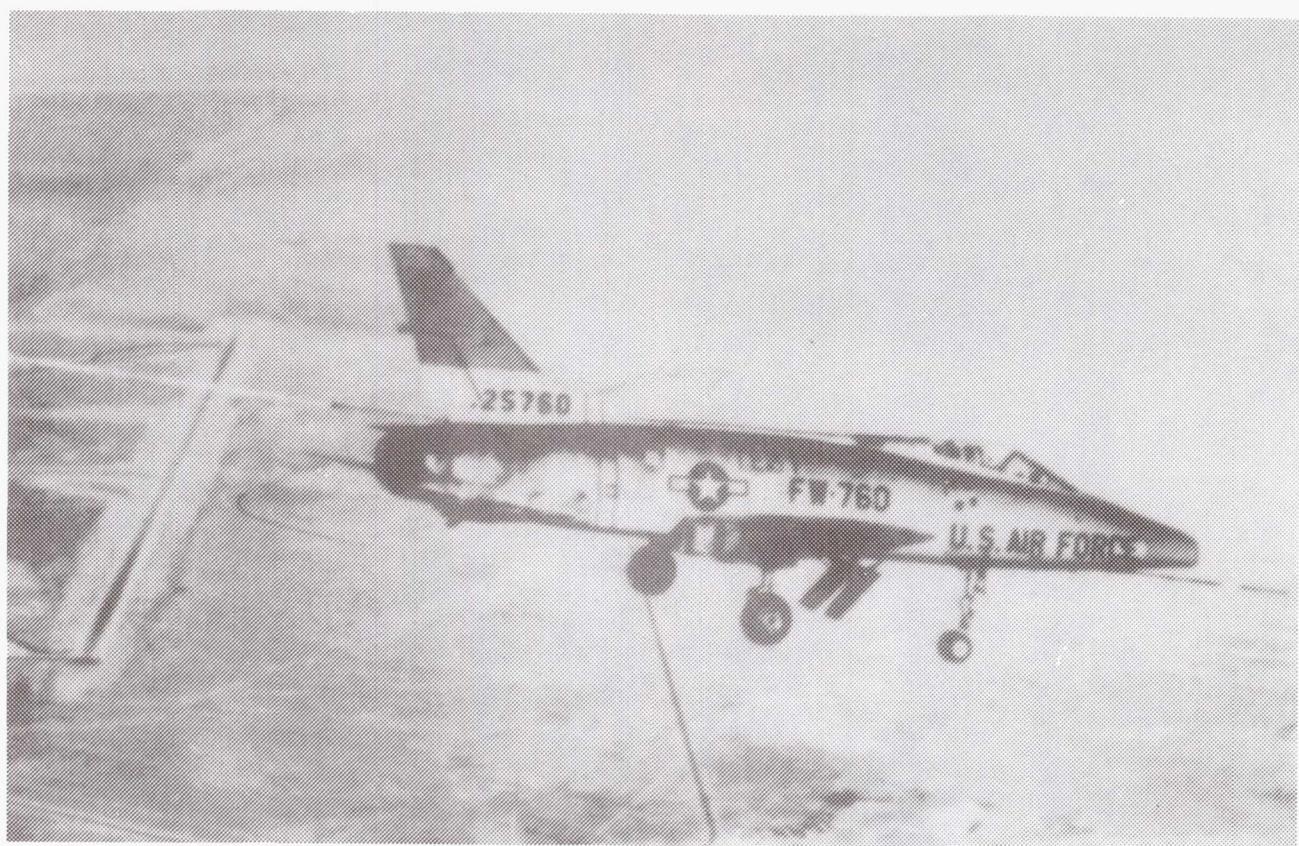


Figure 8. F-100 simulates X-15 low L/D.

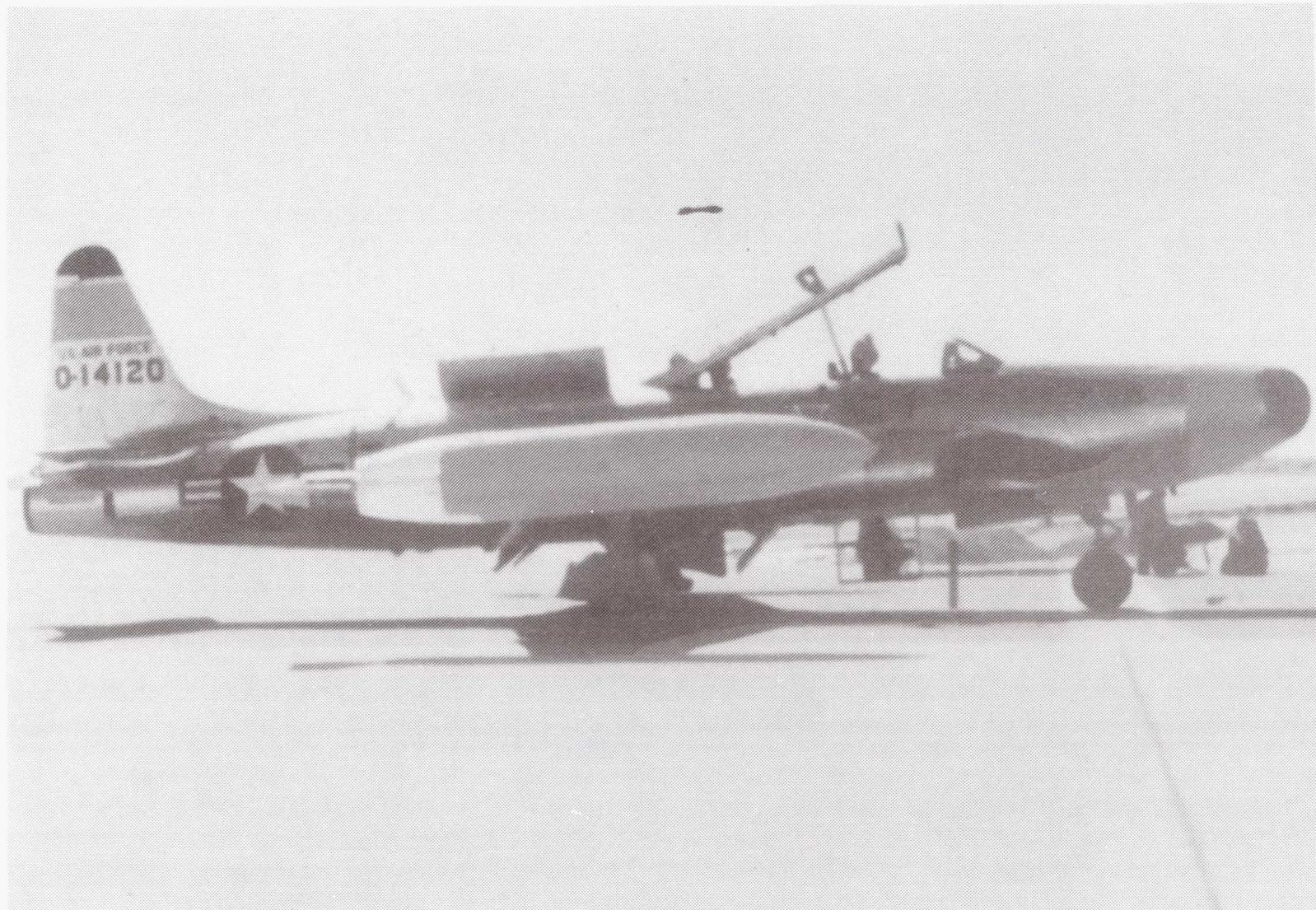


Figure 9. Calspan variable stability T-33 aircraft.

REENTRY VEHICLE EVOLUTION



Figure 10. Reentry vehicle evolution.

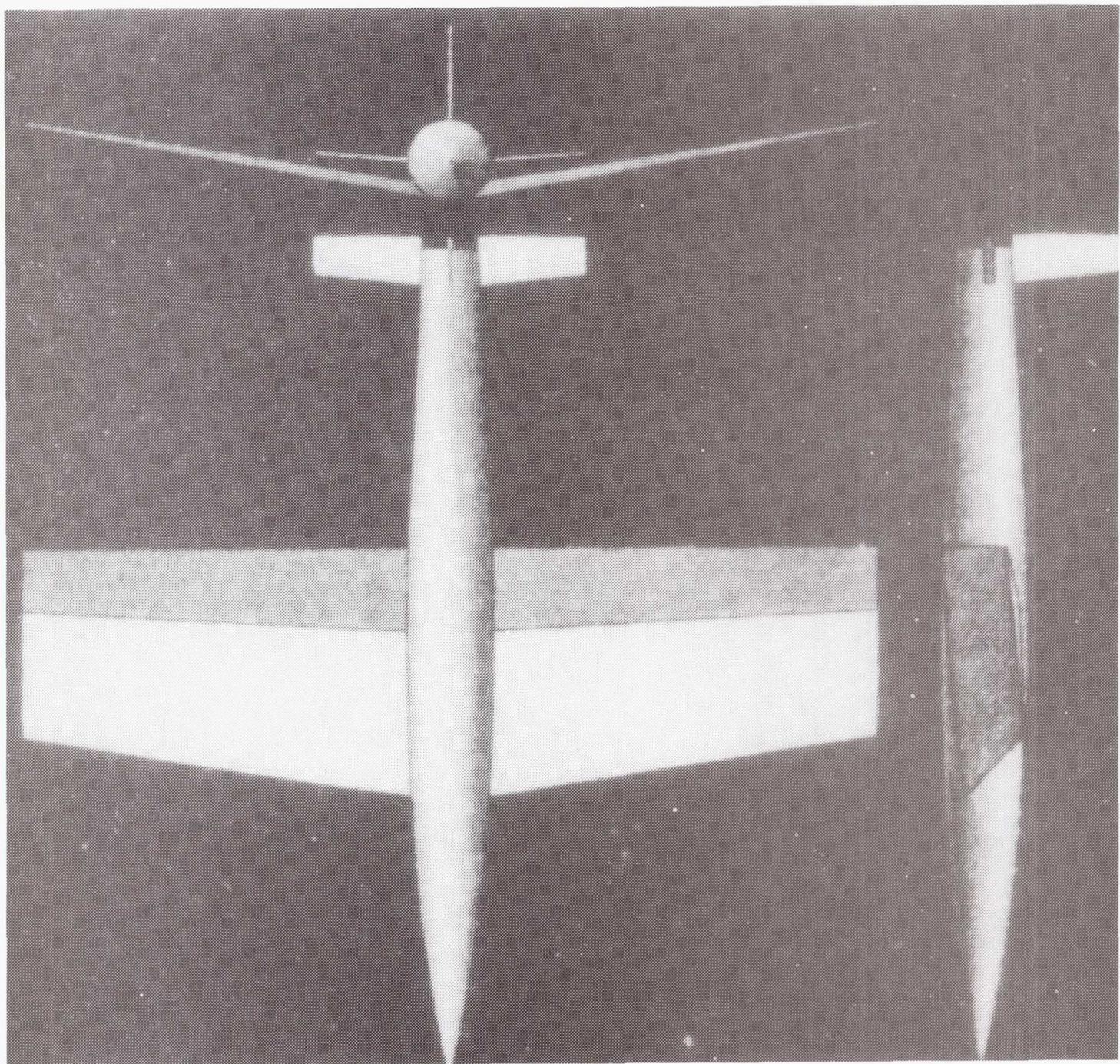


Figure 11. Eugen Sänger's winged hypersonic vehicle design (late 1920's).

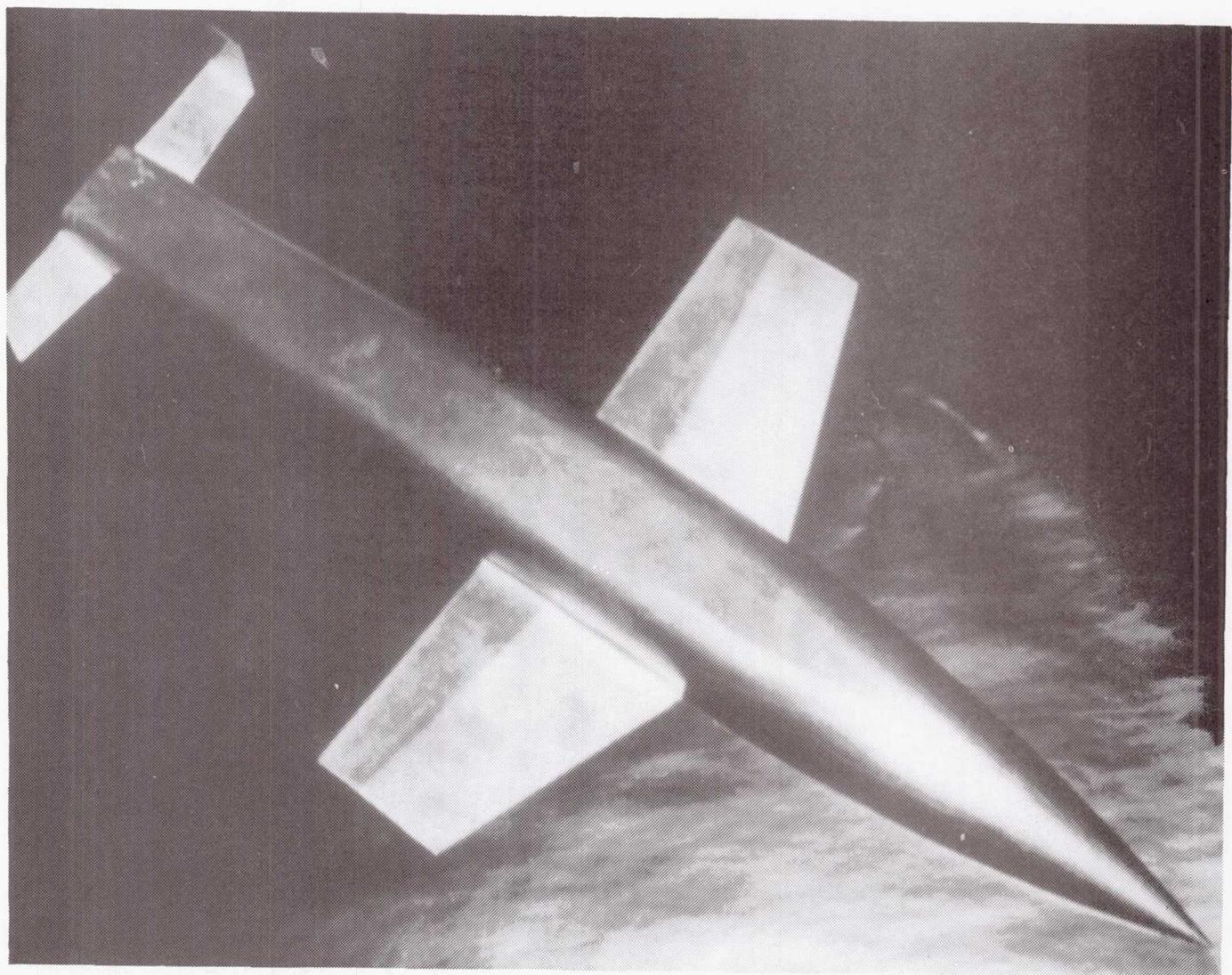


Figure 12. Eugen Sänger's antipodal aircraft design (1930's and 1940's).

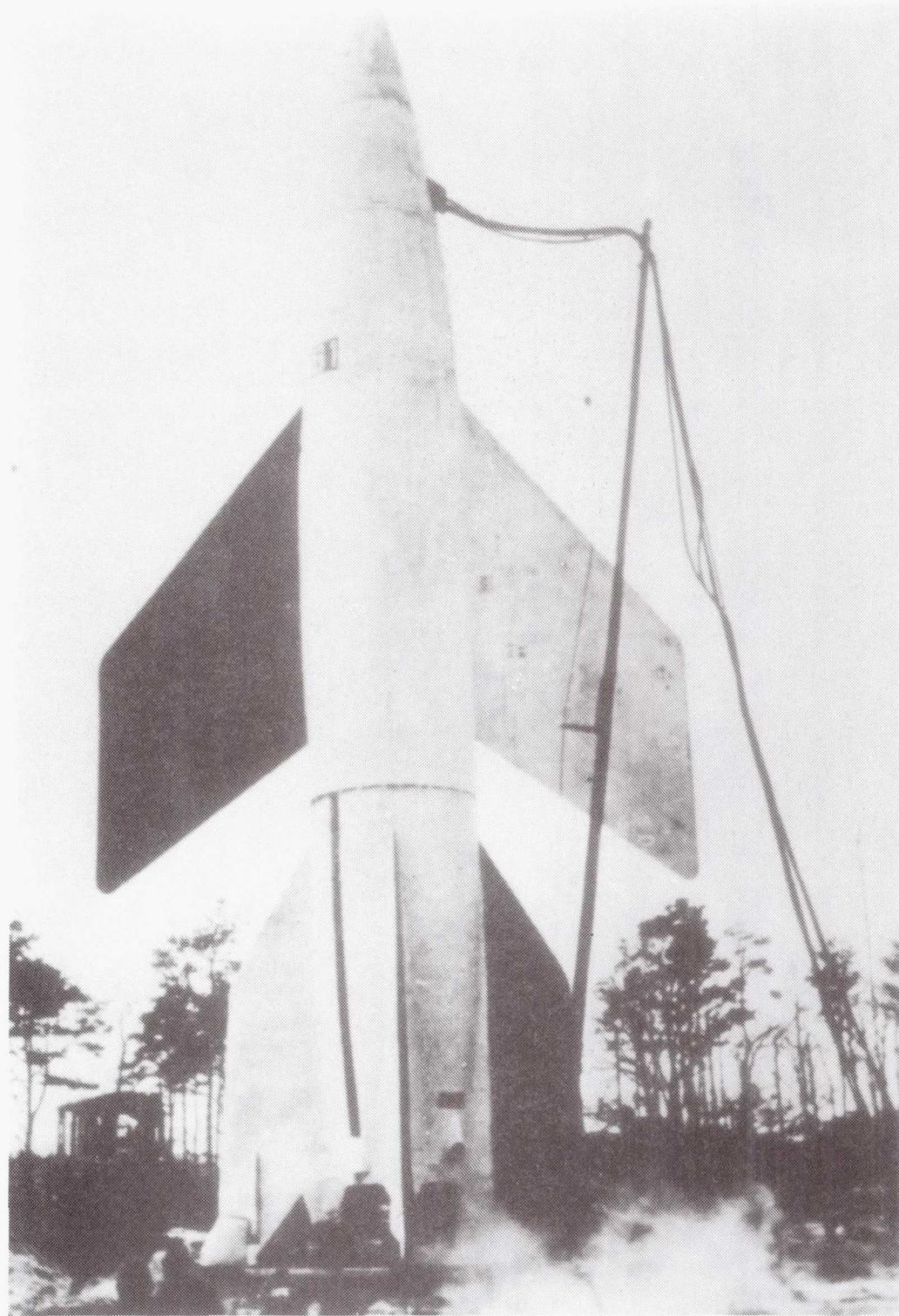


Figure 13. The A-4b test vehicle of 1945.

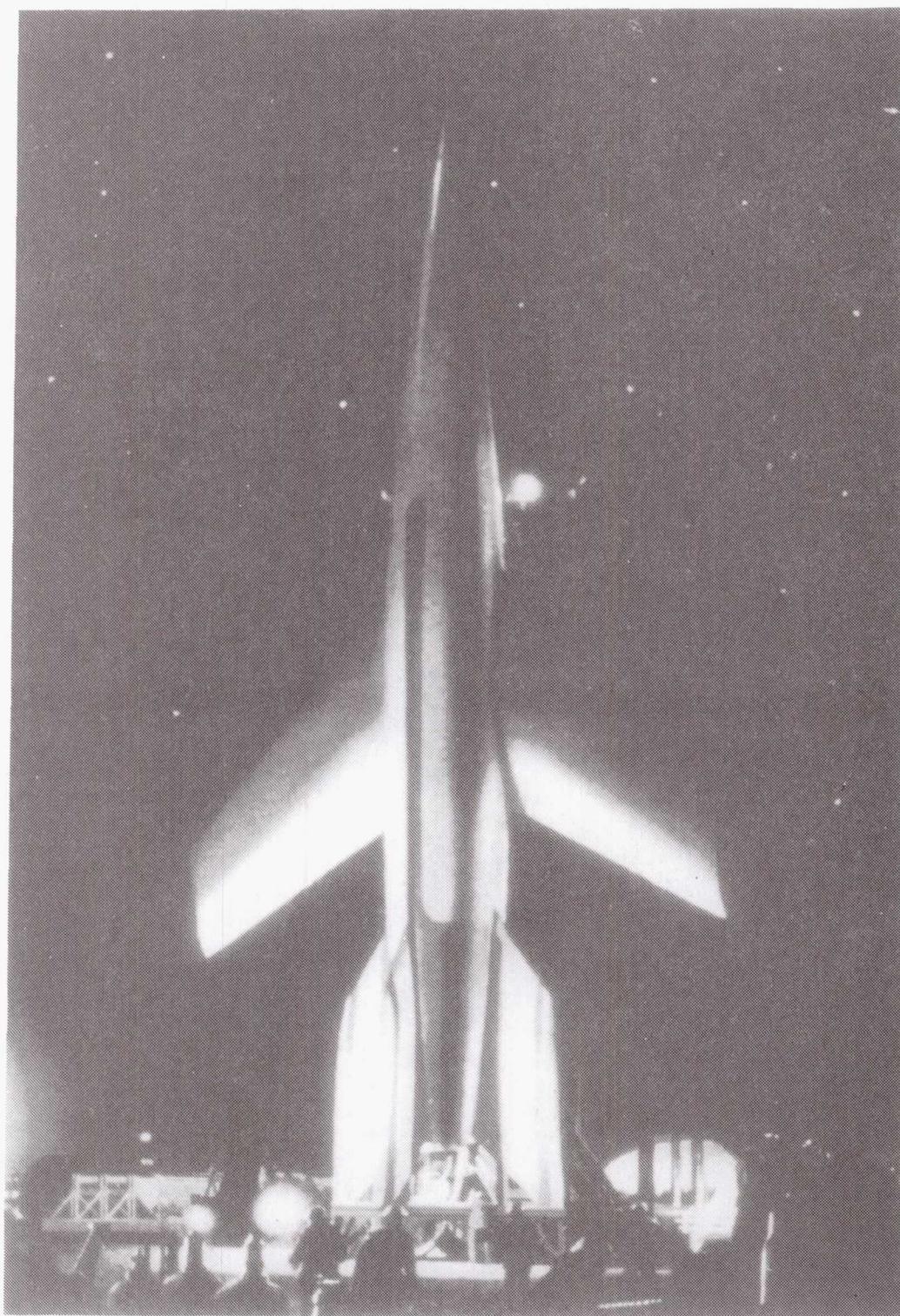


Figure 14. Artist Chesley Bonestell's supersonic winged vehicle at launch.

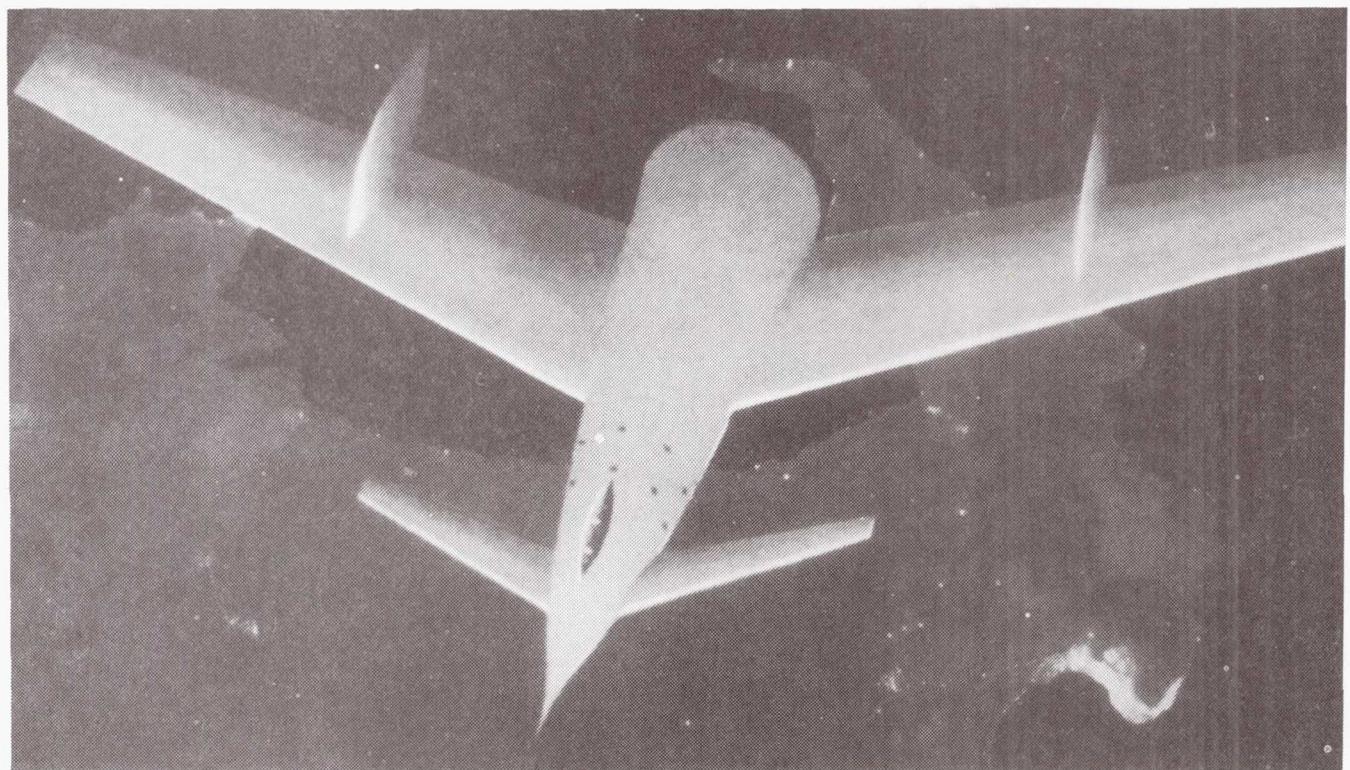


Figure 15. Artist Chesley Bonestell's supersonic winged vehicle reentry.

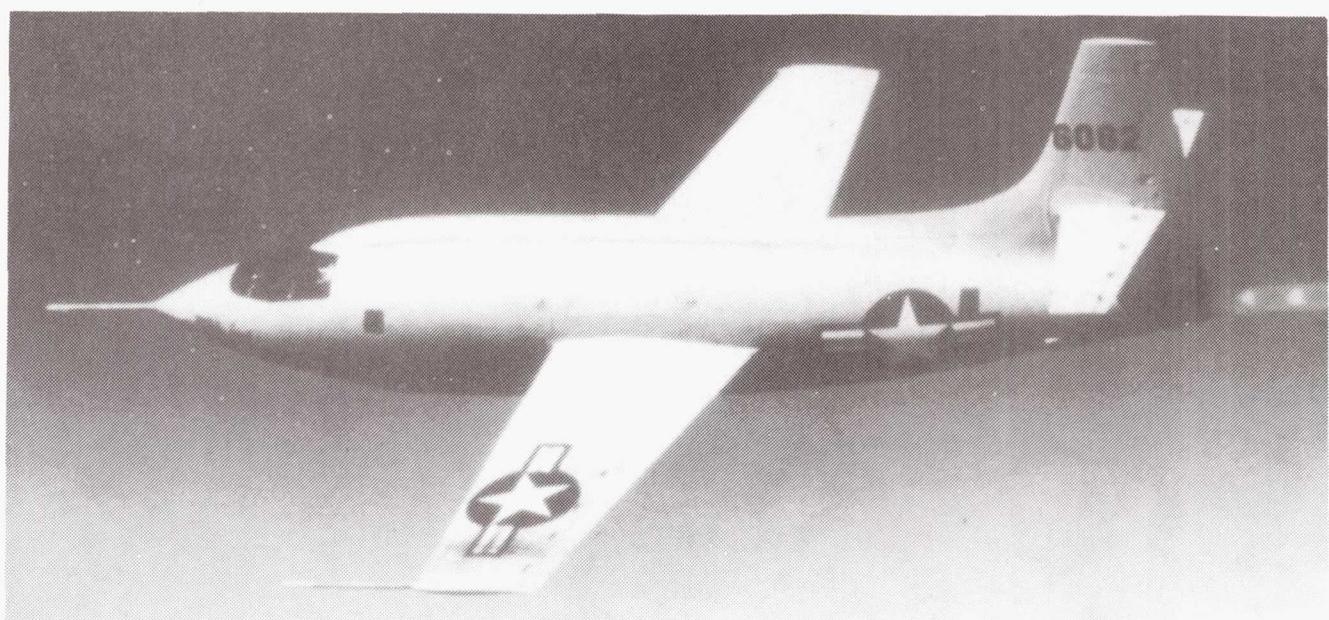


Figure 16. The X-1 supersonic research aircraft.



Figure 17. The early X-series aircraft.

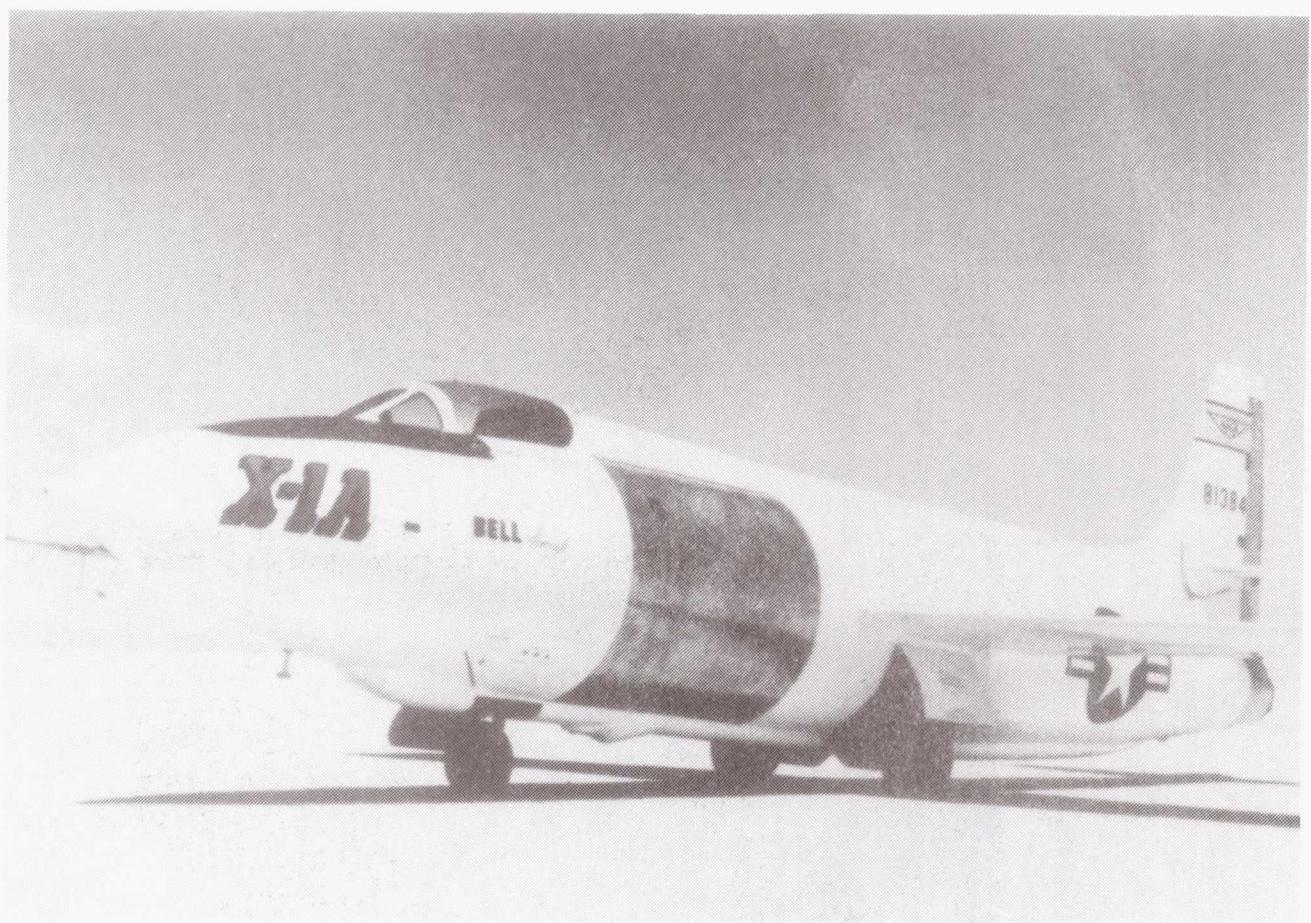


Figure 18. The X-1A aircraft.

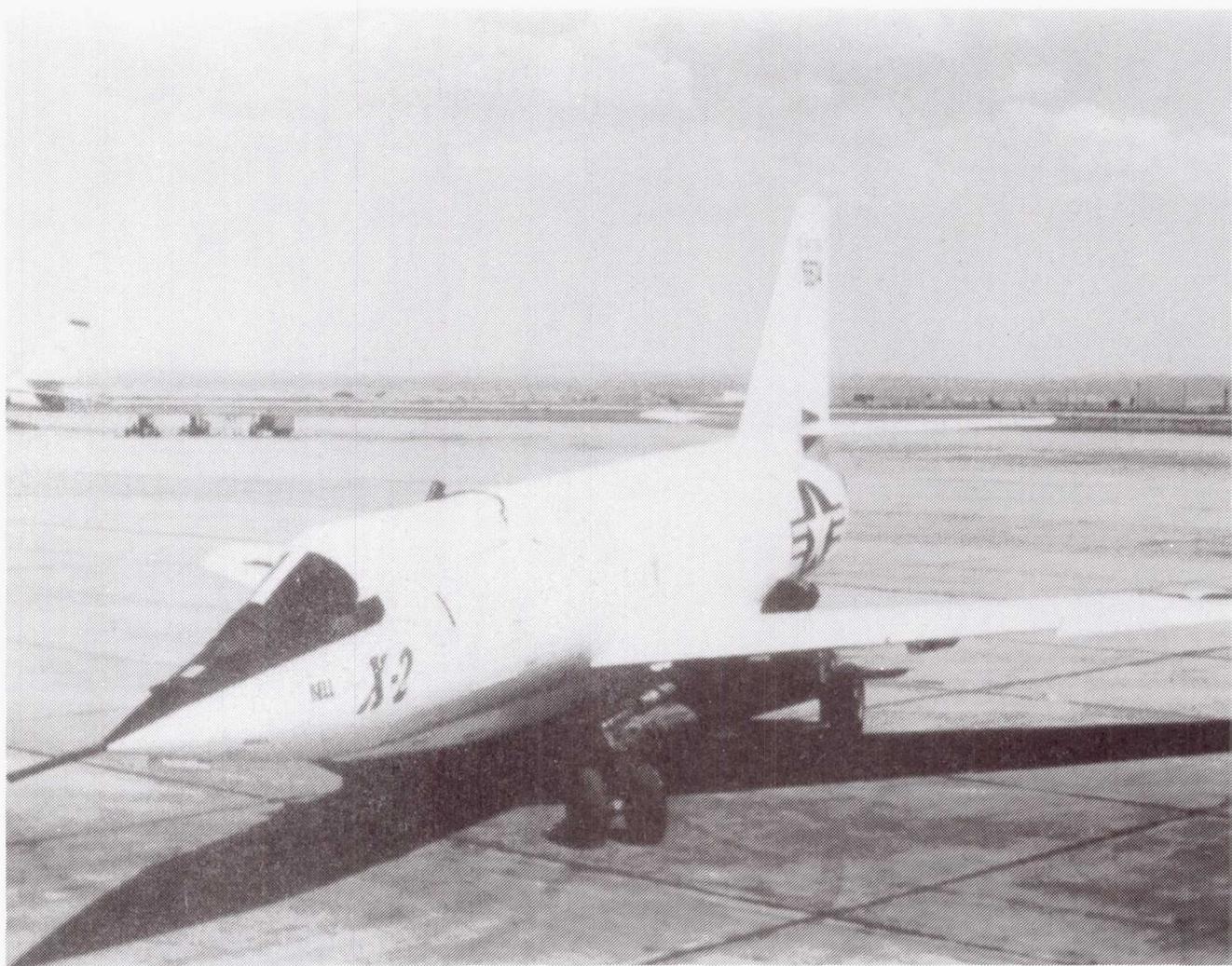


Figure 19. The X-2 aircraft.



Figure 20. Artist's concept of the Douglas D-558-3 aircraft.

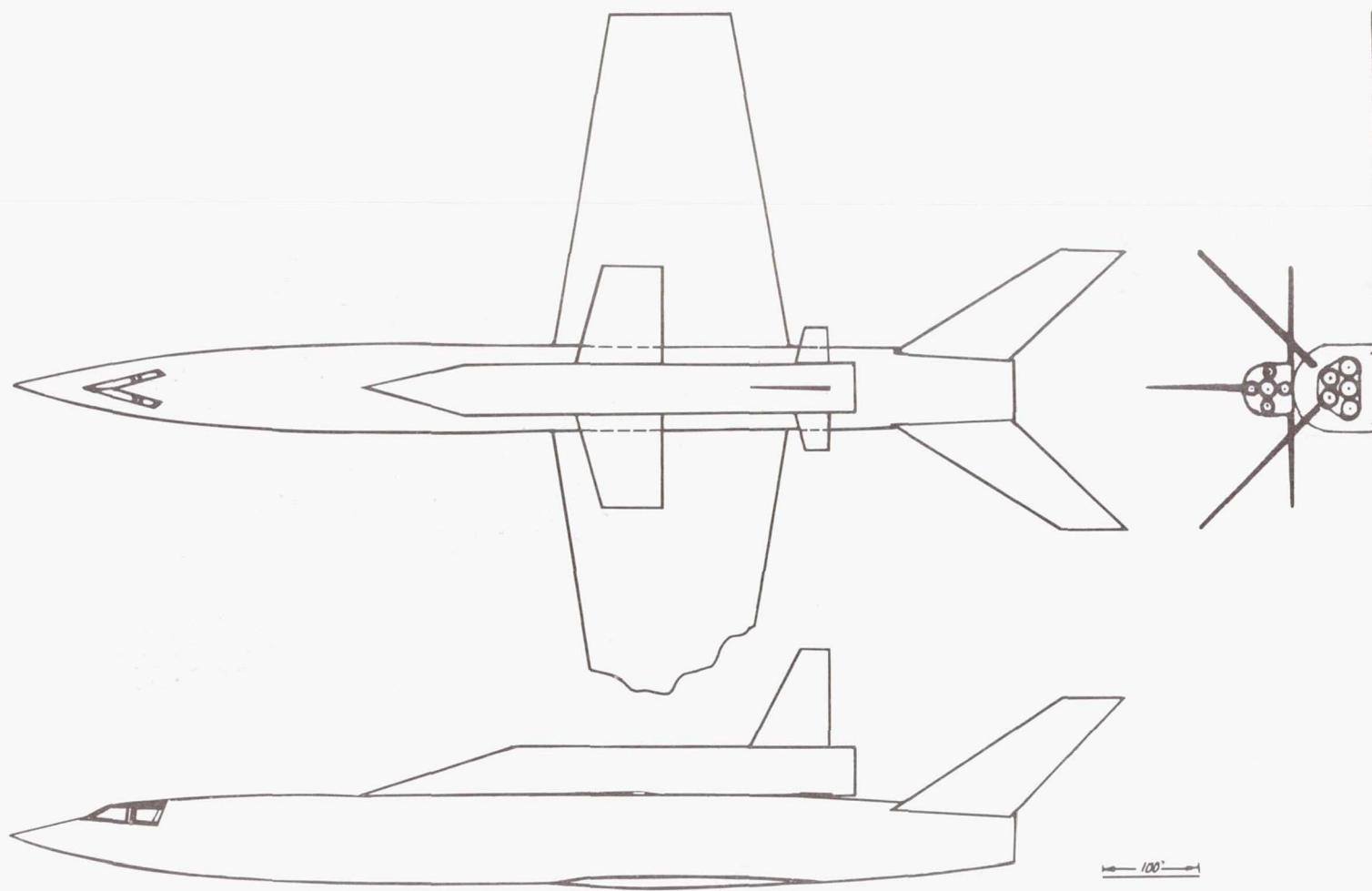


Figure 21. The Drake-Carman studies two-stage design.

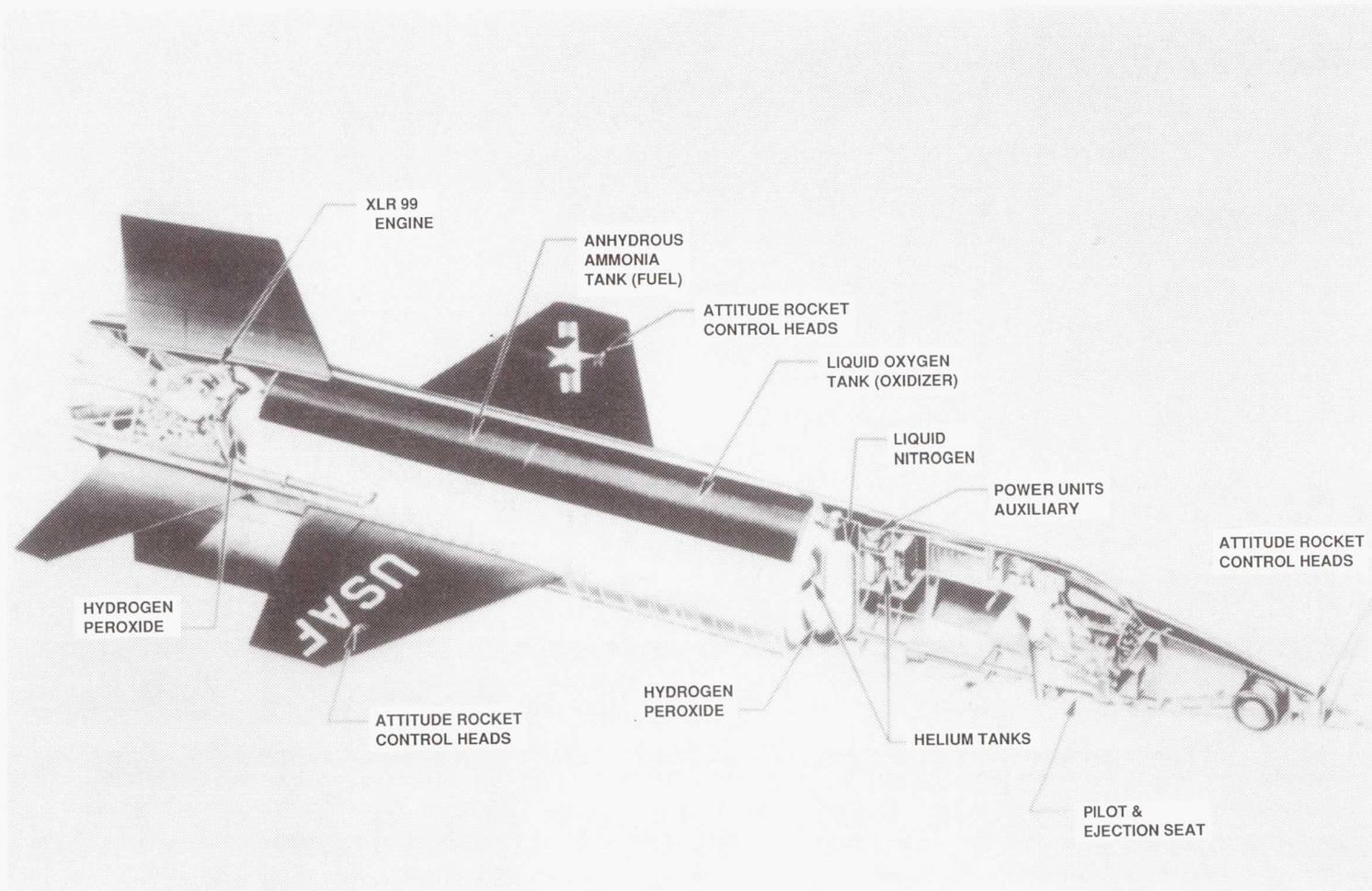
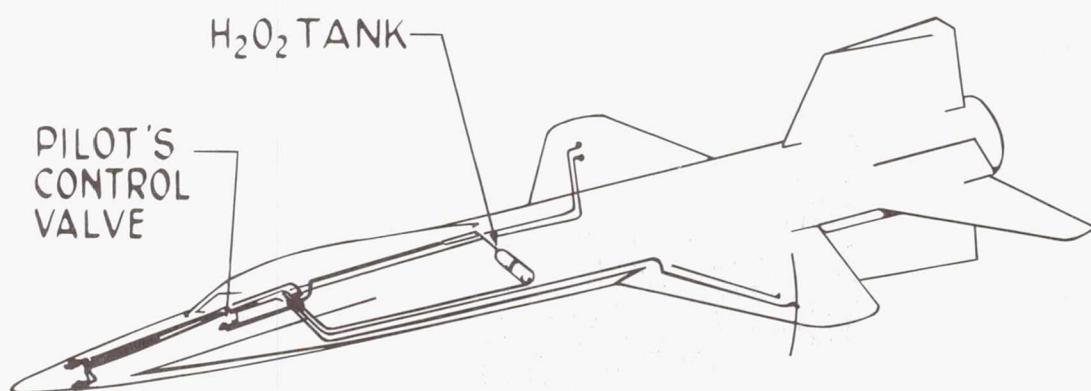


Figure 22. The X-15 aircraft general arrangement.

BALLISTIC CONTROLS



<u>EACH SYSTEM</u>	<u>ACCELERATION</u>	<u>THRUST</u>
PITCH	2½°/SEC ²	113 LB
YAW	2½°/SEC ²	113 LB
ROLL	5°/SEC ²	50 LB

Figure 23. Ballistic controls.

X-15 AERODYNAMIC HEATING

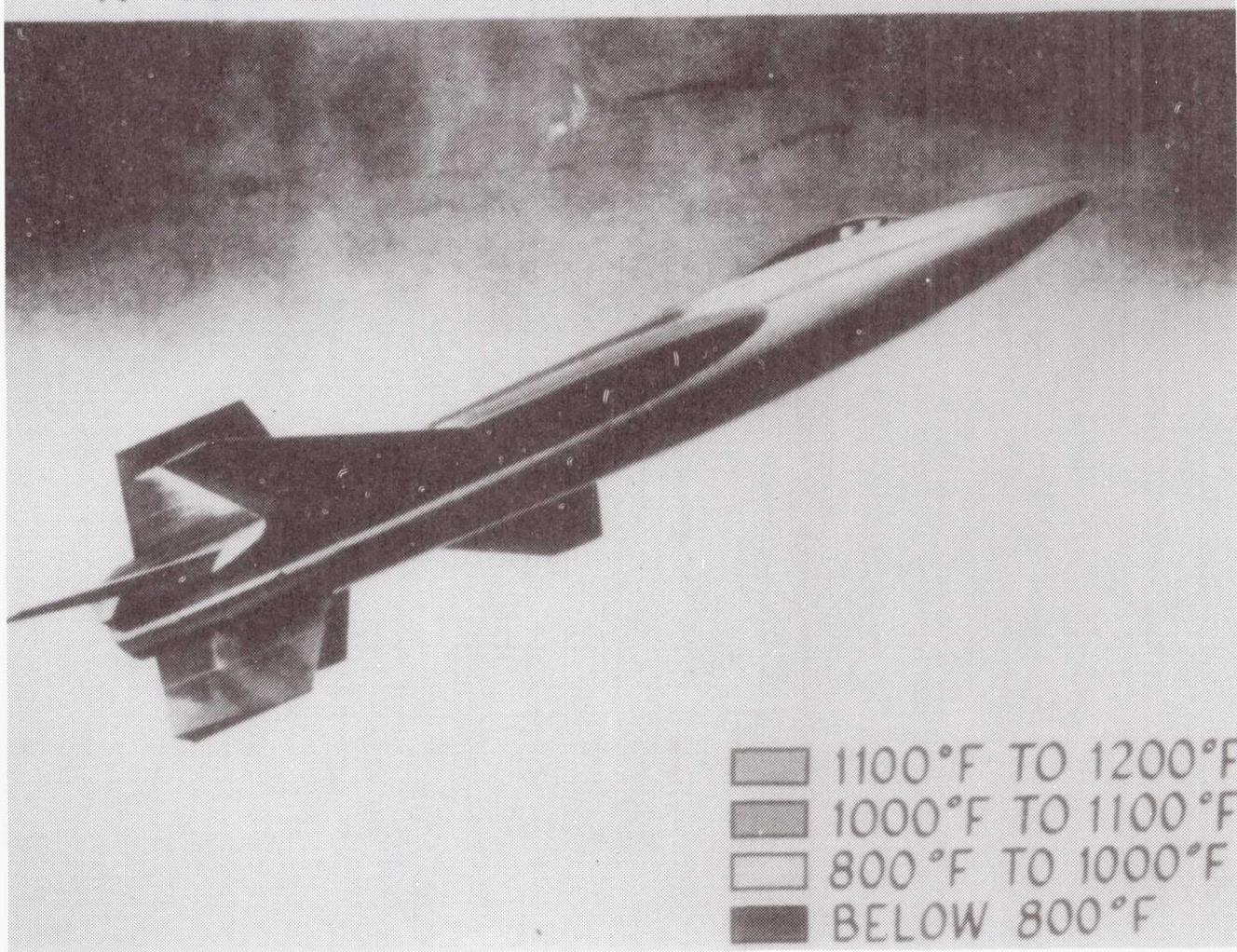


Figure 24. X-15 aerodynamic heating.



Figure 25. The X-15 aircraft ready for launch.



Figure 26. Research pilot Scott Crossfield.



Figure 27. Research pilot Pete Knight.

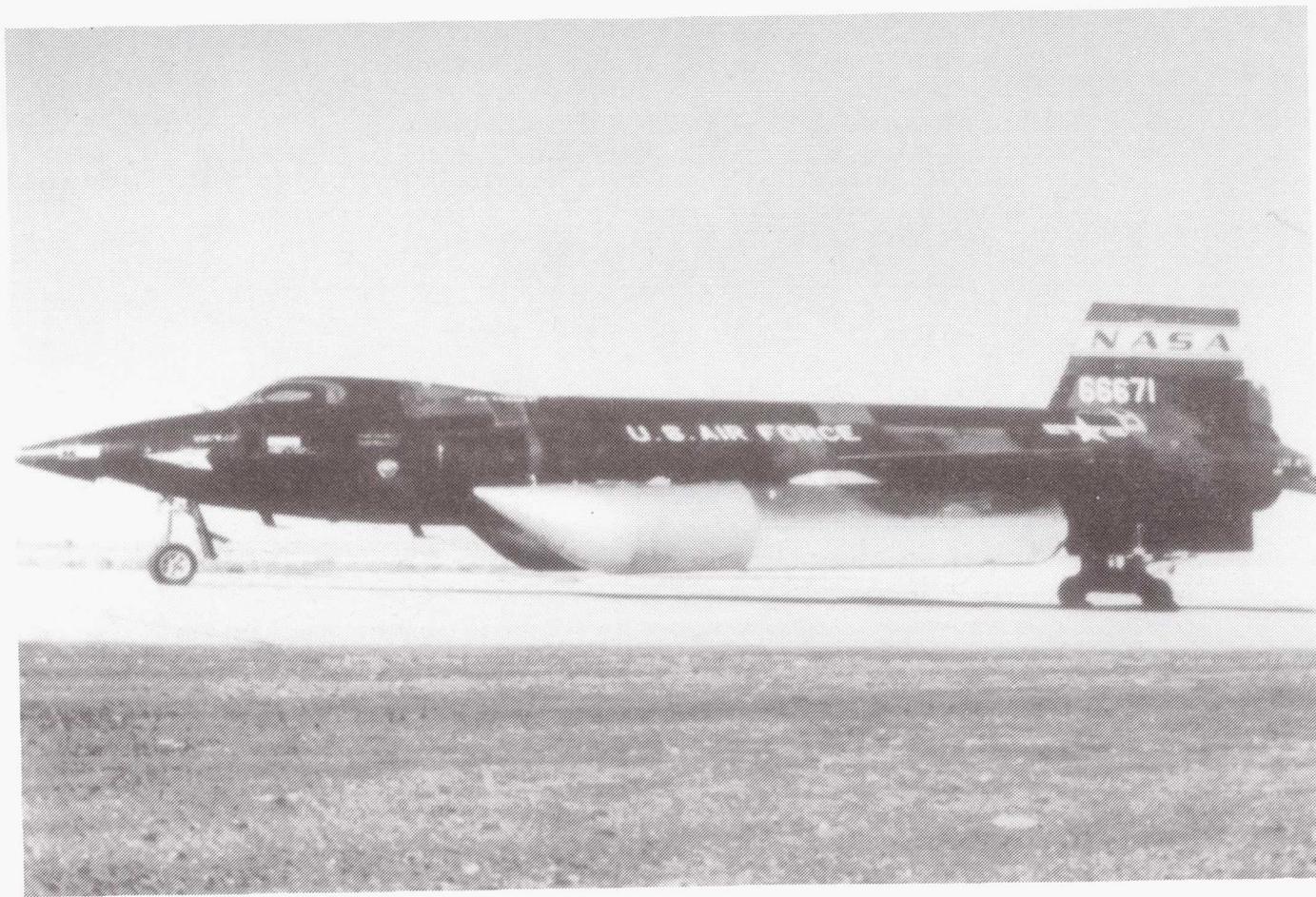


Figure 28. The X-15A-2 aircraft with external fuel tanks.



Figure 29. Research pilot Bob Rushworth.

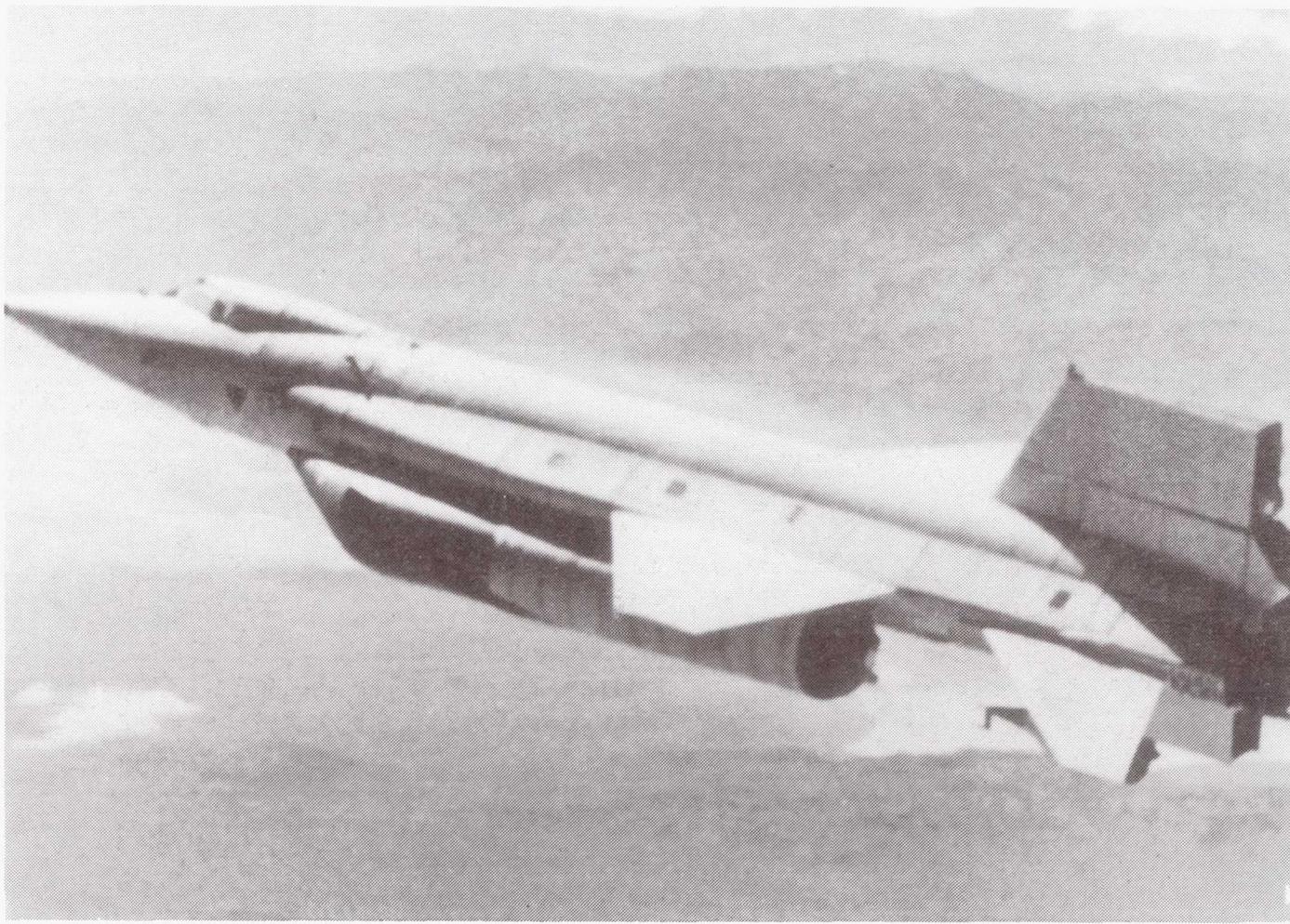


Figure 30. The X-15A-2 aircraft in flight.

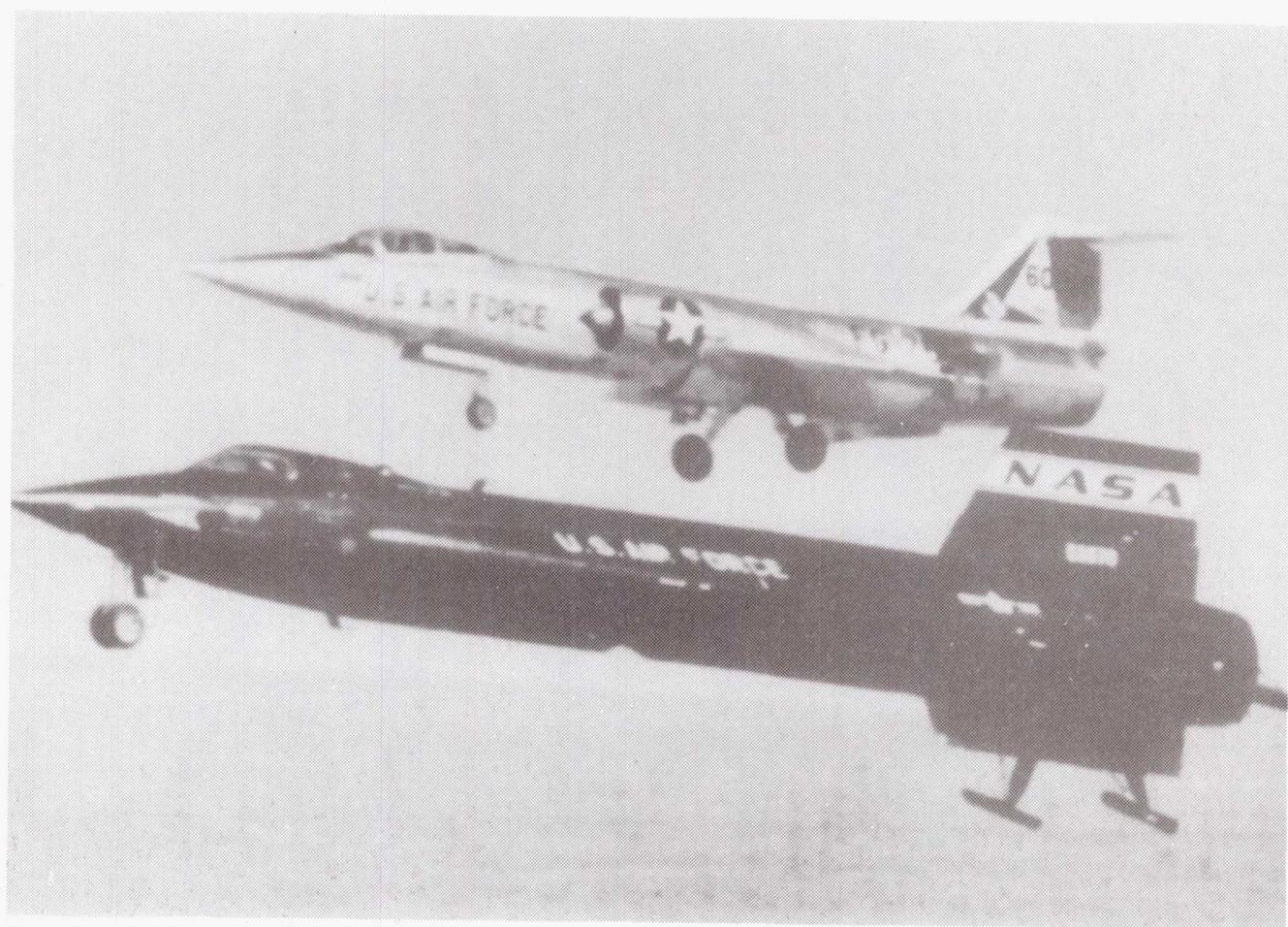


Figure 31. High-impact loading occurs at landing.

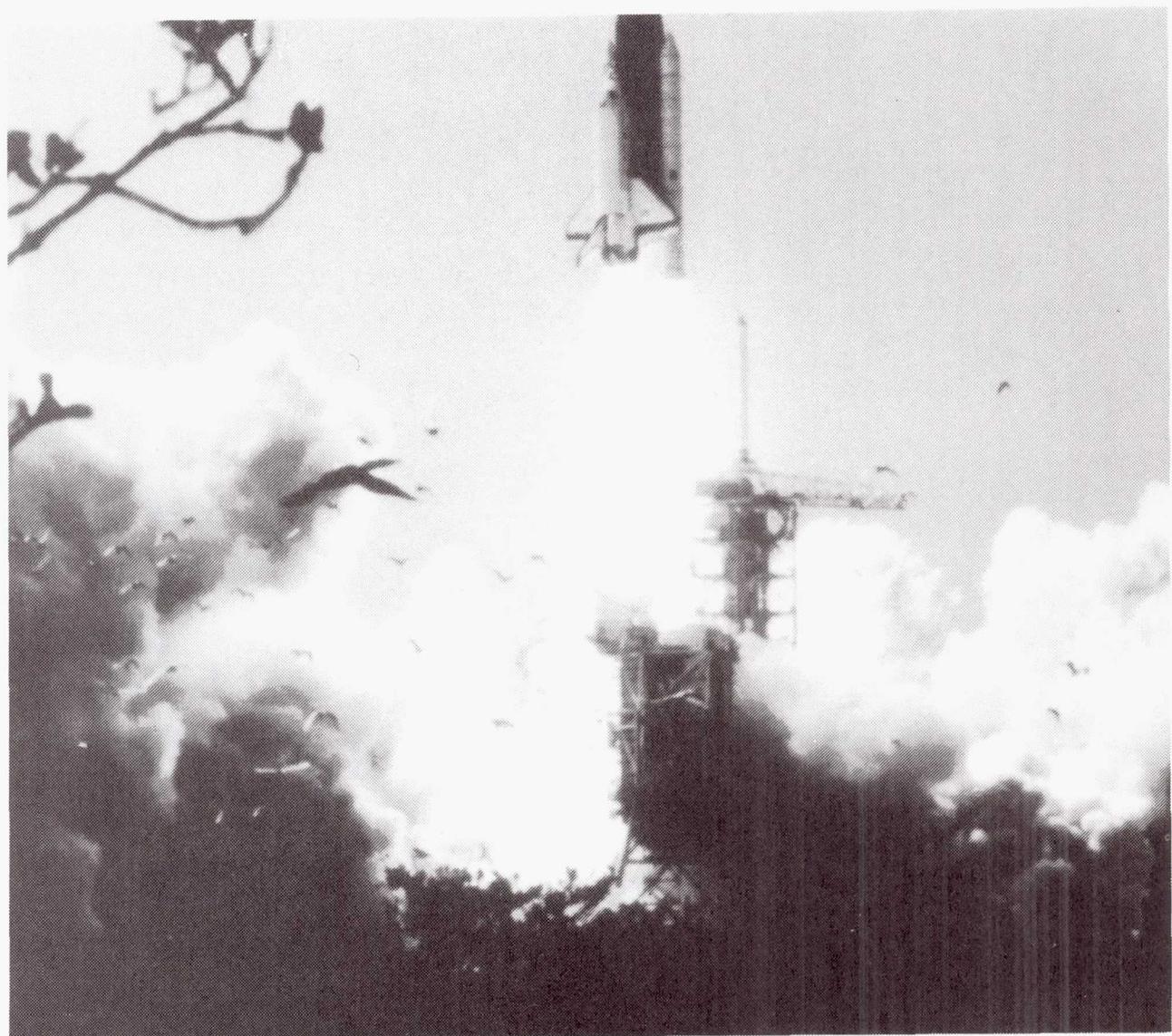


Figure 32. Space shuttle launch.

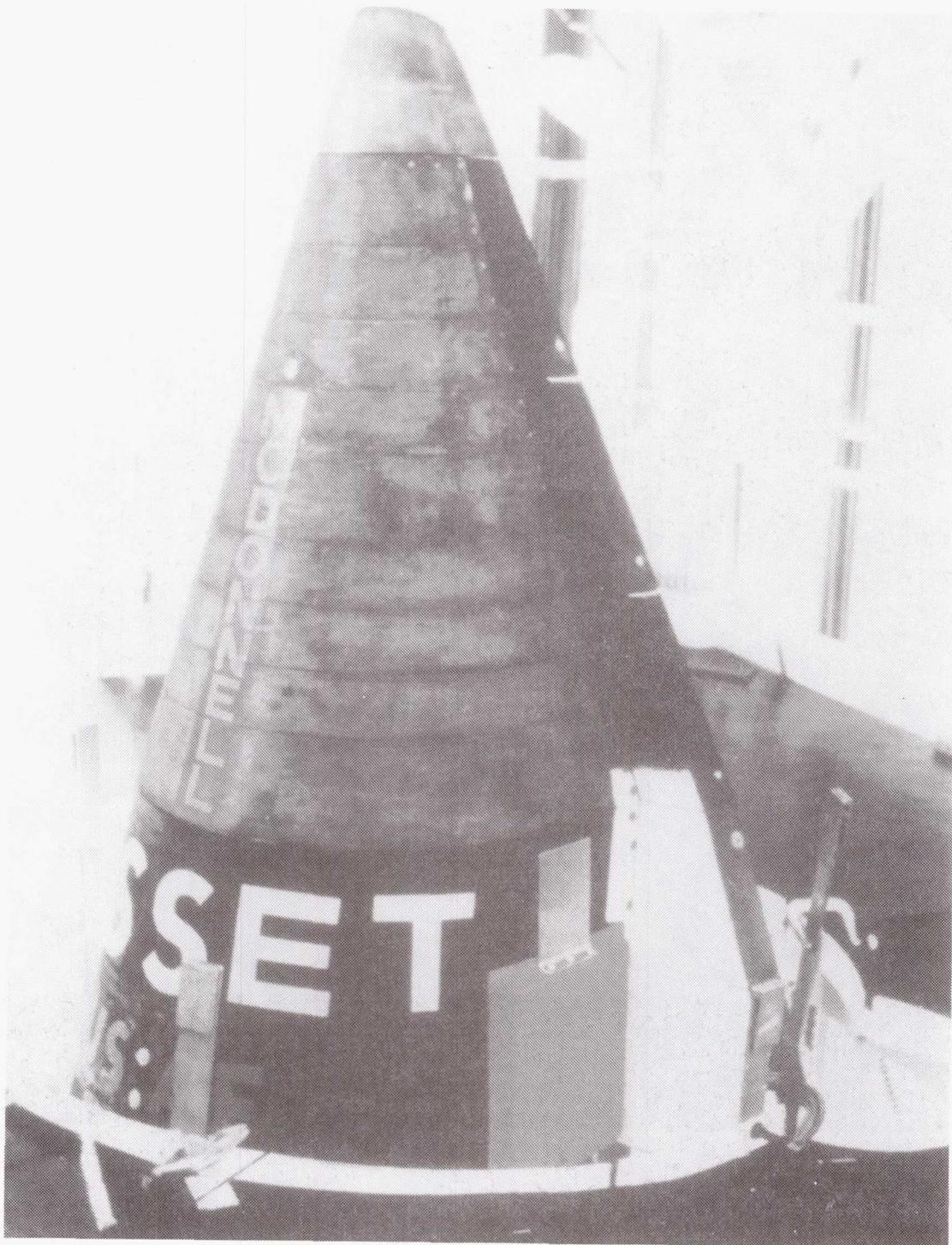


Figure 33. The ASSET program test vehicle.

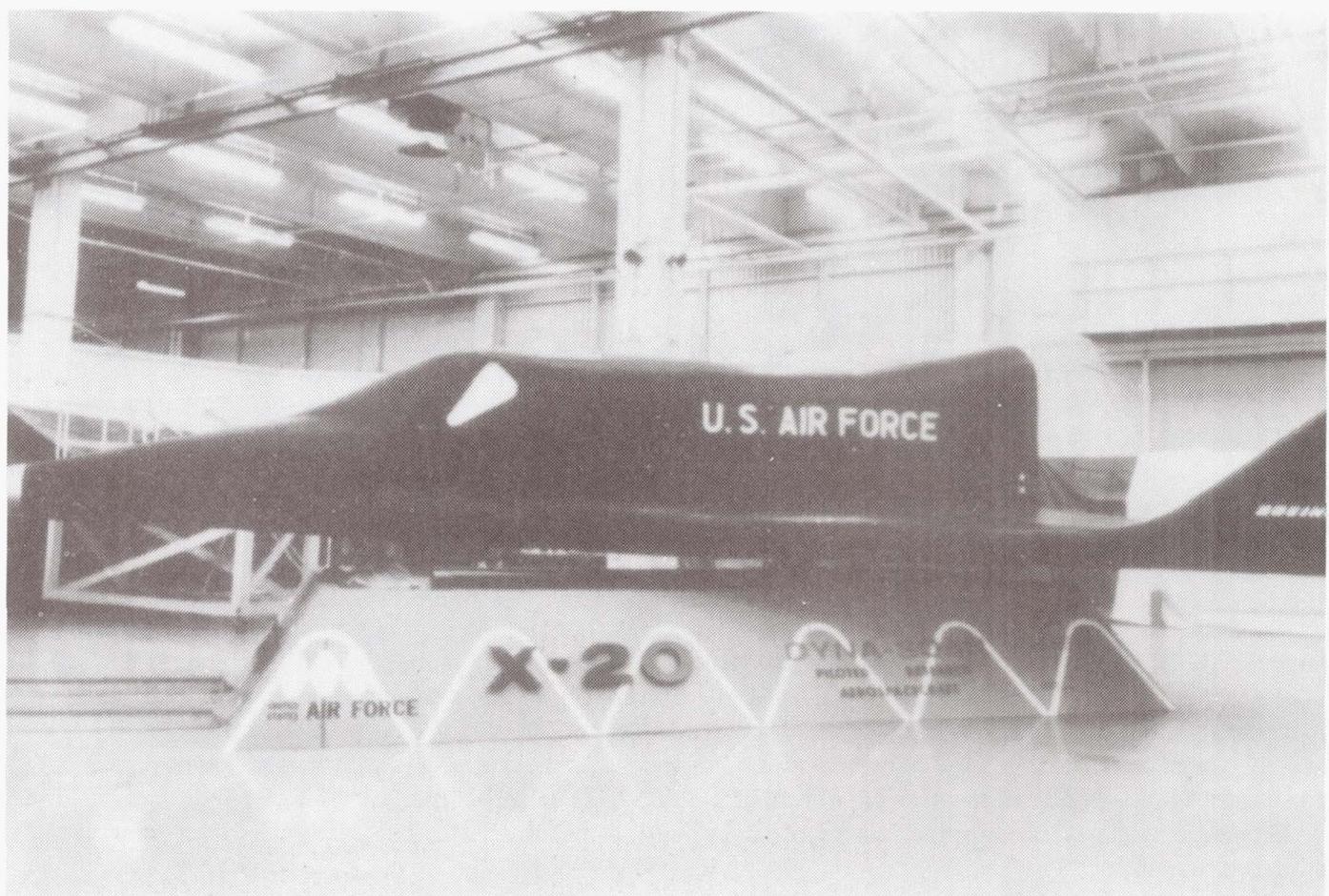


Figure 34. The X-20 Dyna-Soar.



Figure 35. X-24B lifting body.